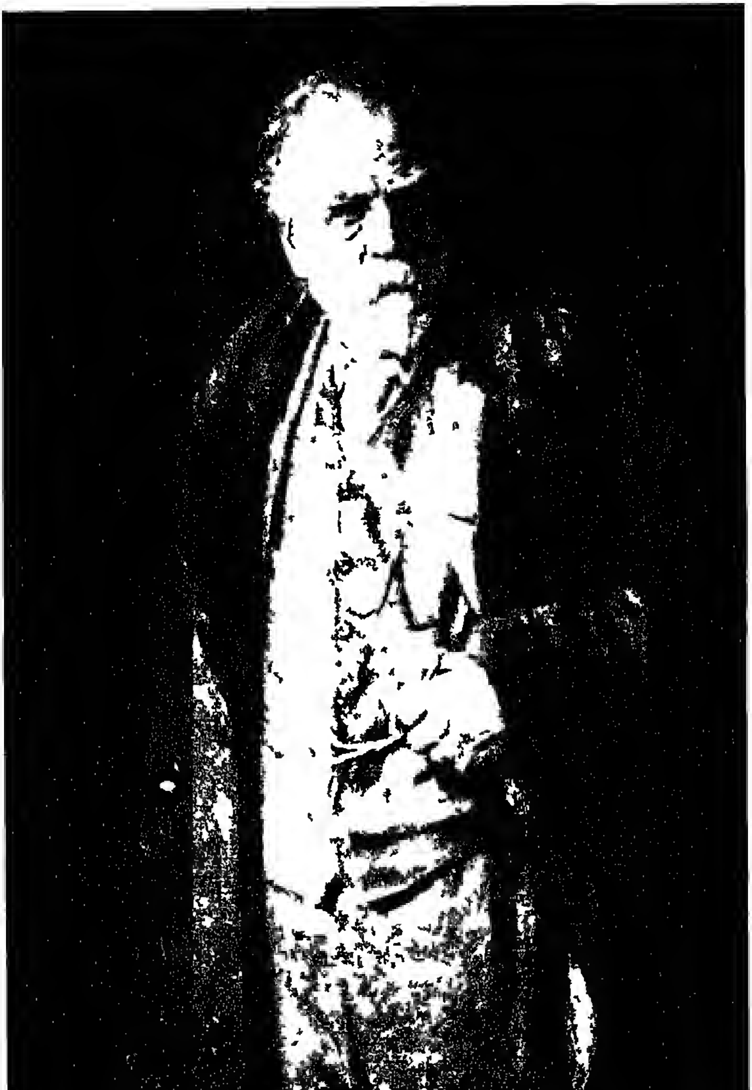
SCIENCE OF THE SEA



SIR JOHN MURRAY

SCIENCE OF THE SEA

AN ELEMENTARY HANDBOOK OF

PRACTICAL OCEANOGRAPHY

FOR TRAVELLERS, SAILORS, AND YACHTSMEN

PREPARED BY

THE CHALLENGER SOCIETY

FOR THE PROMOTION OF THE STUDY OF OCEANOGRAPHY

ORIGINALLY EDITED BY

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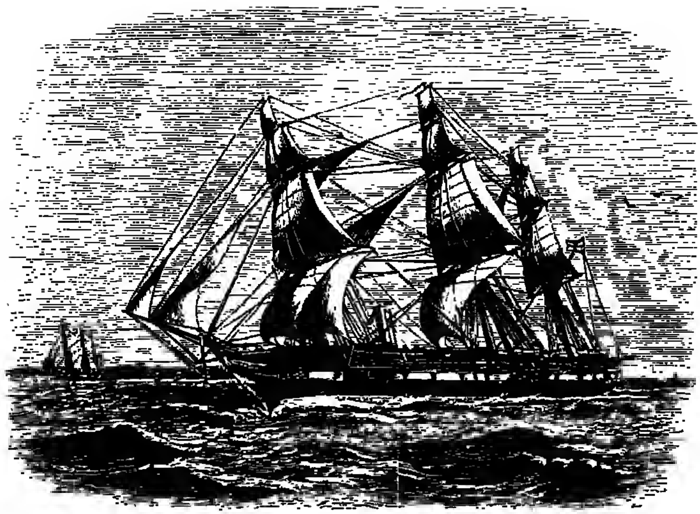


FIG. 1. H.M.S. *Challenger*, 1873–6

PREFACE TO THE FIRST EDITION

NOT seldom those who are engaged in oceanographic work are asked by some one about to start on a long voyage: 'How can I do some work for science? I don't know anything about it; where can I "read it up"?' Such seekers after knowledge might often do most valuable work, even in waters which they would expect to be quite well known. In this study yachtsmen, and officers of the Royal Navy, who are apt to find time heavy on their hands in port or on a foreign station, could enjoy an ever-fresh interest in the sea, its workings, and its inhabitants; even officers of the Merchant Service could find time to help, especially in meteorological and surface-water work. To all such this handbook is primarily addressed: to those who are willing to take observations, but fear that a lack of scientific training will render their work or their collections worthless. Any one who follows the lines here laid

down may feel certain that his work will have real value, that he is building a sound brick into the pyramid of human knowledge. In order still further to promote the work, the Challenger Society has named an advisory committee of specialists in various branches of oceanography, to whom may be referred through the Honorary Secretary inquiries upon points which are beyond the elementary scope of the handbook. But all who propose to take observations, in whatever branch, are strongly advised to spend a few days at one of the marine stations (pp. 468–74), in order thoroughly to understand the practical work.

However valuable the information in this handbook may prove to be, it must remain elementary. It is no 'royal road'; in no sense will it do away with the serious study which all those must undergo who, not content merely to record observations, wish also to grasp the usefulness and meaning of what they are doing. But the book may fairly claim to have brought between two covers instructions, of which many are not in print, and the rest are scattered and hard to find.

The indiscriminate use by the writers of Fahrenheit and Centigrade, metres and fathoms, will prepare the reader for what he will find in the literature of the subject; an oceanographer must be able to think in either scale.

The selected list of manufacturers and tradesmen (p. 486) should prove of value to the beginner.

The object of the volume is severely practical—what to do, and how to do it—written in language which, as far as possible, takes no previous scientific training for granted. The headings of the various chapters sufficiently explain the general plan. With a single exception, they have been written by Fellows of the Society; to the exception—Mrs. Dr. A. Weber-van Bosse, the wife of an

Honorary Fellow, and herself distinguished for researches on Algae—the Society desires to express its special indebtedness. To those who have allowed the use of existing illustrations (notably to Sir John Murray, who placed the blocks of the Reports of H.M.S. *Challenger* at our disposal; and to Mr. S. Henshaw, Curator of the Museum of Comparative Zoology at Cambridge, Mass., who allowed the use of blocks from 'Three Cruises of the *Blake*'), as also to numerous manufacturers who have freely supplied valuable information, the Society also renders its thanks.

The first edition of such a work as this is necessarily of a tentative nature, and the Editor will gratefully receive corrections and suggestions of all kinds for a future issue.

G. H. F.

ASPLEY GUISE,
BEDFORDSHIRE,
April, 1912.

PREFACE TO THE SECOND EDITION

IN preparing the Second Edition of 'Science of the Sea' for the Challenger Society, the general plan of the First Edition has been followed, though several of the chapters have been entirely rewritten and others considerably revised to bring them abreast of modern developments.

Chapter I, on the Air, has been rewritten by Mr. Brunt and Commander Garbett, the superintendents respectively of the Army and Navy Meteorological Services at the Air Ministry. Mr. D. J. Matthews of the Hydrographic Department of the Admiralty has contributed in Chapter II a new and up-to-date account of the physical and chemical problems of sea-water, to which are added sections on alkalinity and on the minor constituents of the water by Dr. W. R. G. Atkins.

Professor Stanley Gardiner has also provided an entirely new account of tropical shore collecting and of coral reefs and islands for Chapter III.

Of the two sections of Chapter IV, that on floating plants, by Dr. Marie Lebour, is new, whilst that on fixed plants, by Dr. Weber-van Bosse, has been rewritten.

Chapter V, on floating animals, has been revised by Mr. E. T. Browne. The late Sir John Murray's chapter (VI) on the sea floor has been reprinted as originally written by him, with the addition of an occasional footnote referring to later work.

Chapter VIII has been revised by the authors; and Chapter IX, where necessary, by Mr. F. M. Davis and myself; Chapter X, by the original author, Mr. L. W. Byrne; and Chapter XI, on the preservation of Marine Organisms, by Mr. E. T. Browne and myself.

Professor D'Arcy Thompson has largely rewritten Chapter XII, on Whales, Seals, and Sea-Serpents. The last Chapter (XIII), on Logs, Notes, and Labels, which was contributed by Dr. G. H. Fowler to the first edition, has been reprinted without change. Dr. L. A. Borradaile has provided a revised Classification Table of Animals, the corresponding table of Plants being reprinted as before.

To all those who have contributed to this revised edition of the handbook the thanks of the Challenger Society are due, as well as to Mr. F. S. Russell, who with great skill and care has assisted the editor in seeing the book through the press.

E. J. A.

Marine Biological Laboratory,
Plymouth.
May 1928.

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF CHARTS

Between these extremes of scale—between the gigantic and world-embracing movements of Air and Water, and the brief life of the minutest organism—lie, intricately interwoven, the problems with which the student of oceanography must wrestle. But while his proper work is the orderly marshalling of facts into groups, as a basis for explanations—or at least for hypotheses—the facts themselves can be gathered in quantity by any traveller who chooses to take the trouble of doing so.

I

THE AIR

By D. Brunt and L. G. Garbett

The atmosphere in which the earth is embedded is a mixture of gases, the main constituents being nitrogen (78 per cent.) and oxygen (21 per cent.). There are other constituents present in small quantities, but except for water vapour and possibly for ozone, they are not of importance in the study of the motions of the atmosphere.

It is a relatively rare thing to observe air to be at rest for any considerable period. Its normal condition is one of motion, and air in motion is wind. Over the surface of land the motion of air is complicated by the effects of contour and of the general roughness of the ground, which give rise to swirls and eddies in the same way that a rock in a stream does. Over the sea the motion of air is not complicated by contour, though it is likely that waves on the surface of the sea have a similar effect to that of the general roughness of ground in level country. It is certain, however, that over the sea the motion of air is of an essentially simpler nature than its motion over land. There is an additional reason for this apart from the lack of contour. The surface of the sea is a uniform flat surface, having everywhere the same capacity to absorb, reflect, and radiate heat, whereas on land the power of absorption, radiation, or reflection differs for different types of surfaces. The power to absorb the heat rays of the sun differs very considerably for desert sand, grassland, bare soil, woodland, &c., and these inequalities give rise to considerable complexities in the motion of air over the earth.

The motion of the air over the sea is free from such complications, and it might appear at first sight that at sea

the meteorological observer should find the most favourable conditions for the study of the air and its ways. In practice, however, this is not the case, for the simple reason that instrumental observations of all kinds are far more difficult to carry out on board ship than on land. The movement of the ship makes the observation of the wind with extreme accuracy practically impossible. Allowance has to be made for the course and speed of the ship, and, if the wind is measured by means of an anemometer, the rolling and pitching of the ship introduces errors into the records. The measurement of temperature is also troublesome, as care has to be taken that the air which reaches the thermometers has not come into earlier contact with any part of the ship. In general it can be stated quite definitely that the greater apparent simplicity of the problem of meteorology over the sea is more than counter-balanced by the difficulties in the way of accurate observation.

It may not be an exaggeration to say that civilization began when man began to take note of the weather, to observe the regular changes of the seasons, and to arrange his life in accordance with these. The men of the open air have in all ages been forced to take special note of the weather and its changes. The sailor and the farmer have been habitually weatherwise. But so long as the weather remained an individual study the observer's weather knowledge was limited by his own horizon. He could only take note of what he actually saw. The invention of the barometer led to the formulation of a number of rules for forecasting the weather, but real progress in meteorology came with the introduction of the synoptic chart about the middle of the nineteenth century. The development of telegraphy made the synoptic chart a practical possibility, and it was almost immediately recognized that meteorology should be developed from an international

standpoint. The progress made was rapid, and the chief features of the weather chart as we know it to-day had become established by about 1870.

At the same time it was recognized that charts showing the conditions over the oceans would confer enormous benefits on the seafaring interests of the world. At the instigation of Admiral (then Lieutenant) Matthew Fontaine Maury, U.S.N., an International Conference was held at Brussels in 1853, and a plan of observations to be followed on board ship was recommended. This plan was adopted by practically all the seafaring nations of the world. Maury was the author of a well-known book, 'Physical Geography of the Sea', a book which is still well worth reading. It is a book which is thoroughly imbued with the spirit of scientific research, and marked by the boundless enthusiasm of its author, and though some of its facts are out of date, and the theoretical treatment appears fantastic in the light of the knowledge acquired since its appearance, it remains a model for writers of popular science.

Some Properties of Atmospheric Air

It will be well, before we try to describe the motions of air over the globe, to fix in our minds some of the physical properties of atmospheric air. Dry air, i.e. air from which water vapour has been removed, no matter where it is sampled, except near factory chimneys or other sources of pollution, is made up of the same gases in the same proportion. Normally, however, air contains a quantity of water vapour, and the amount of water vapour changes from place to place, and from time to time in any one place, and it is no exaggeration to say that the larger part of meteorology is concerned with the study of the vagaries of the water vapour in the atmosphere.

The amount of water vapour which a sample of air can hold depends solely on the temperature of the air, and is independent of the pressure. Now water vapour is lighter than dry air, in the ratio 5 to 8. When water vapour is introduced into air, it displaces an equivalent amount of dry air, so that the density of the resulting damp air is less than that of dry air at the same temperature and pressure. Damp air then is lighter than dry air, just as warm air is lighter than cold air. Air is relatively very light compared with water. (Air at ordinary pressures and temperatures has a density about $\frac{1}{800}$th of the density of water.) The weight of air above a square inch of ground is about 14 lb. This is equal to the weight of a column of mercury a square inch in cross-section and about 30 inches high. We thus commonly speak of normal atmospheric pressure as being roughly equivalent to 14 lb. per square inch, or to 30 inches of mercury. The measurement of pressure by means of a mercury barometer simply consists in balancing the pressure of the air against the weight of a column of mercury, and measuring the length of the column. This is true whether we express the pressure in inches, millimetres, or millibars.

The pressure of air falls off with increasing height, and at 18,000 feet it is only half the pressure at the ground, while at 36,500 feet it is only about one quarter the pressure at the ground. This means that of the total mass of the atmosphere one half is below the level of 18,000 feet, and three-quarters is below the level of 36,500 feet. These figures are average values. Where the temperature is high, and the air therefore less dense than the average, the rate of decrease of pressure with height is less than the average.

If a portion of air is heated to a higher temperature than the surrounding air, it will become lighter than the

surrounding air, and will tend to rise, its place being taken by cooler air. The rising air carries its excess of heat with it. This method of transferring heat from one place to another by the bodily transfer of air is called the convection of heat, and rising currents produced in this way are called convection currents.

Convection is not the only process by which heat can be transferred by the air. When the earth is heated by the sun, it radiates upward some of the heat it receives and this radiation is to some extent absorbed by the water vapour in the air. The air in turn can radiate out in all directions at least a portion of this heat. Only to a minute extent does air transfer heat from one place to another by ordinary conduction, in the sense in which heat is conducted from one end of a hot poker to the other end. This type of transfer is carried out by molecules handing on some of their energy to their neighbours, and in a gas the distance between neighbouring molecules is too great to allow of this being done to any considerable extent.

The earth's atmosphere can be regarded as a colossal machine, whose motive power is derived from solar radiation. The complexity of the motion of the air over different regions of the earth is due in the first place to the variation with latitude of the amount of solar radiation received at the ground, and in the second place to the differences in the capacity for absorbing or radiating heat possessed by different portions of the earth's surface. Again, the amount of heat necessary to raise the temperature of a given mass of water through one degree is from four to five times the amount of heat required to raise the same mass of dry soil through one degree. This is one of the reasons why changes of temperature over the sea are so much less than those over land.

The differences between land and sea are so funda-

mental and so far-reaching in their effects that it is desirable to form a clear idea of their causes. When the sun is low, its rays are almost entirely reflected from the surface of the ocean, and so sent back into space without having any heating effect upon the sea. When the sun is high, its rays penetrate into the water to a considerable depth. The heating effect is thus spread through a large mass of water, and this, added to the fact that a given amount of radiation produces a relatively small heating effect in water, accounts for the absence of any considerable heating of the sea surface during the day. At night the sea surface radiates heat quite readily, but when the surface layer is cooled it tends to descend, and so spreads the cooling effect through a considerable depth, with the result that the actual surface temperature of the sea does not show any marked drop during the night.

Thus the temperature of the sea surface should show no marked diurnal variation such as is shown by a land surface. There must naturally be a small diurnal variation, but it is too slight to be readily measured. In the same way, the differences of sea temperatures in summer and winter are relatively slight by comparison with those of land. The temperature of the sea then is far less responsive to solar radiation than the temperature of land. It is for this reason that oceanic climates are in general less subject to violent extremes of temperature than continental climates.

It must not be overlooked, however, that a continental climate may at times, and in places, extend out to sea. For example, in winter the winds blowing out of the Siberian anticyclone across the China Seas are intensely cold. In the British Isles, on the other hand, the prevailing winds are oceanic winds in summer and winter. Hence the cool summers and mild winters of the British Isles, by com-

parison with the more extreme climates of the middle of a continent.

When the air over a large area is heated from below, it expands, and produces a lower pressure over that area than over surrounding regions. The inverse effect holds when the air is cooled over a large area. The explanation of these phenomena is not quite so simple as to justify its inclusion here. The effect, however, is to tend to produce anticyclones over the continents in winter, and over the oceans in summer.

In Charts I, II, III, and IV are given the mean isobars (lines drawn through points of similar atmospheric pressure) and isotherms (lines drawn through points of similar temperature) for January and July. A very cursory inspection of these maps shows that in middle and high latitudes there is a definite association of anticyclones with continents in winter, and with oceans in summer, and of low pressure with oceans in winter, and continents in summer. The most striking individual effect is the formation of a very large and intense anticyclone over North Eastern Asia in winter, as shown in Chart I, in a position corresponding very closely to the pole of the most intense cold shown in Chart III. There is another centre of very low temperature in winter over Greenland, but this does not produce so marked a pressure effect as the Siberian centre, on account of the nearness of the North Atlantic.

The Fundamental Meteorological Observations

The features of the weather which are ordinarily observed are:

(1) The state of the sky, whether clear or cloudy, and whether rain is falling.

(2) The temperature of dry and wet bulb thermometers. From these two readings, by the use

of tables, we can readily estimate the relative humidity, which expresses as a percentage the ratio of the amount of water vapour actually in the atmosphere, to the maximum amount of water vapour that air of that temperature can hold in the form of true vapour.

(3) Pressure or height of the barometer.
(4) The wind direction and force.
(5) The extent of horizontal visibility, and the presence of mist or fog.

These observations are all of a simple kind and require no special skill.

Instruments

The meteorological instruments usually found on board ship are as follows: Mercurial Barometer, Aneroid, Barograph, Thermometers; other instruments occasionally used at sea are Thermograph, Psychrometer, Raingauge, and Anemometer.

1. The most important of these instruments is undoubtedly the **mercurial barometer** which measures pressure. It is mounted on gimbals, so that it can remain vertical even when the ship is rolling. It must be placed in a position which will allow it to do this and where there is an equable temperature, free from draughts, in a good light and at a convenient height so that the eye can be brought easily to the level of the top of the mercury. The chart house is often the most convenient place for the barometer, but this is not always the case owing to its exposed position and its distance from the centre of gravity of the ship. The 'pumping' of the mercury caused by the movement of the ship in a seaway is reduced in a Marine Barometer by a constriction of the tube at the cistern end. The rise and fall of the ship in a seaway

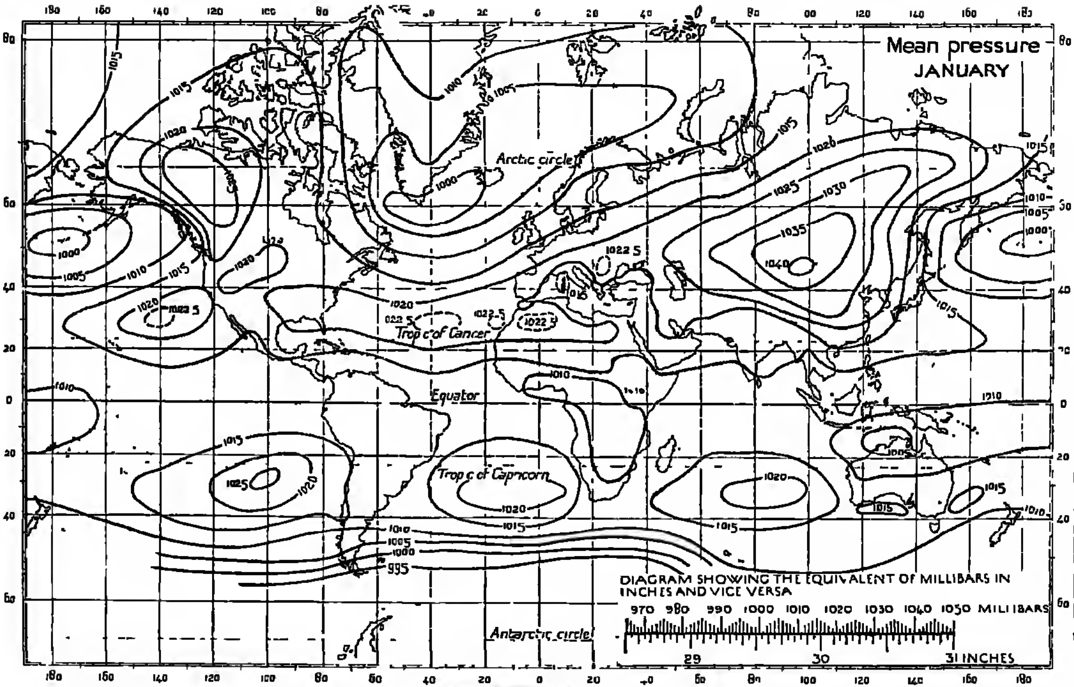

Mean pressure
JANUARY
Arctic circle
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic circle
DIAGRAM SHOWING THE EQUIVALENT OF MILLIBARS IN INCHES AND VICE VERSA
970 980 990 1000 1010 1020 1030 1040 1050 MILLIBARS
29 30 31 INCHES

CHART I

produces a small irregularity, and when it is remembered that roughly speaking the barometer falls one thousandth of an inch for every foot of increase of height, it is plain that the vertical rise and fall of the ship in rough weather may affect the readings by several hundredths of an inch. It is necessary therefore to take the mean of the highest and lowest readings when the ship is in the trough and on the crest of successive waves. It must be remembered that a high degree of accuracy is required in the reading of the barometer when the reading is to be used for plotting on a Synoptic Chart.

Barometers are graduated in inches or millibars, sometimes with both scales. The reading must be reduced to sea level and corrected for temperature and latitude if it is to be plotted on a synoptic chart or is to be transmitted by wireless telegraphy for the information of other ships. (For correction of barometer see 'Barometer Manual'.)

An ingenious device, known as the 'Gold Slide', for automatically correcting the Barometer, is fitted to some barometers and saves reference to the correction tables.

2. The **aneroid** also measures pressure and is a particularly useful instrument in ships as it can often be placed in a position immediately under the supervision of the Officer of the Watch. It is in many ways a more convenient instrument than the barometer but is not so reliable in measuring absolute pressures. The aneroid should be frequently compared with the barometer. The readings do not require correction for temperature or latitude but only for index error and height above sea level.

3. The **barograph** is a self-registering form of aneroid and is a valuable supplement to the barometer, since barograms show minor fluctuations of atmospheric pressure which are seldom noticeable in the action of mercurial

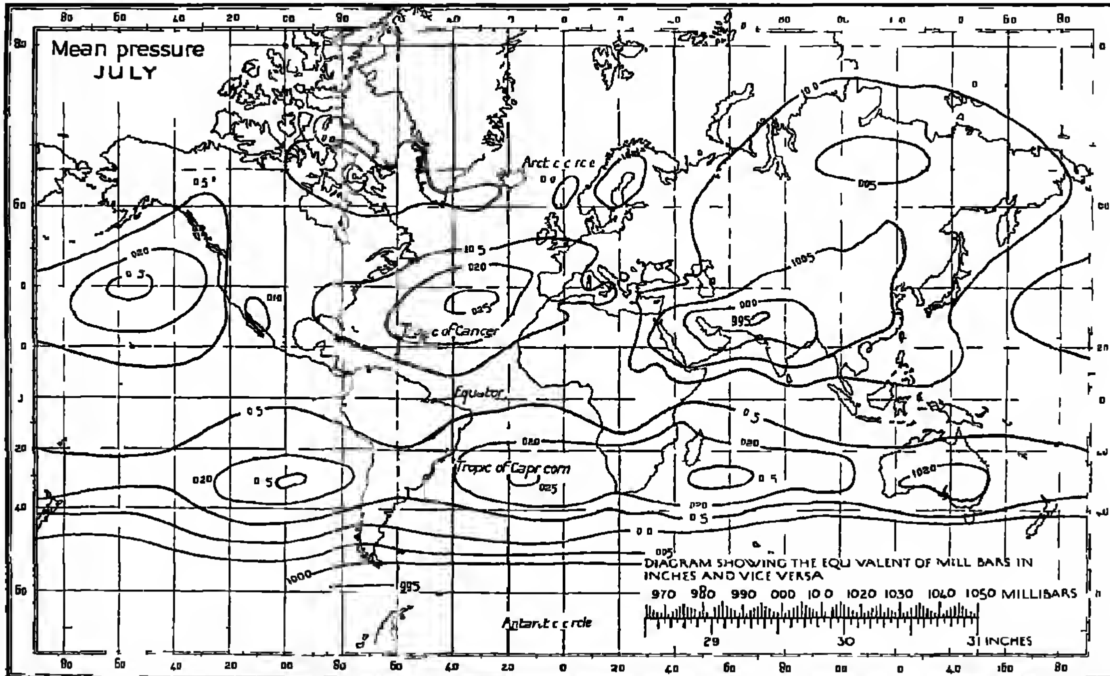

Mean pressure
JULY
Arctic circle
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic circle
DIAGRAM SHOWING THE EQUIVALENT OF MILLIBARS IN
INCHES AND VICE VERSA
970 980 990 1000 1010 1020 1030 1040 1050 MILLIBARS
29 30 31 INCHES

CHART II

barometers. It should be carried in a cradle, sling, or spring suspension bracket and placed in the position least likely to be affected by vibration or movements of the ship.

4. **Thermometers** measure temperature. They should be of standard type, tested at Kew or some other national testing establishment, and supplied with a certificate of accuracy. This condition is insisted on for all instruments supplied by the Meteorological Office.

The **wet and dry bulb** thermometers must be exposed in a louvred screen, quite in the open, free from all artificial heat, and protected from sea-spray and from all risk of injury. The best exposure is usually to be found on the weather side of the bridge. The bulb of the dry thermometer must be kept as free from moisture as possible. The bulb of the wet bulb thermometer is kept moist by means of a covering of fine muslin to which is attached a piece of cotton wick whose lower end dips into a small vessel containing water. This water must be changed frequently to prevent any crustation of salt. A weekly change of muslin is also advisable and the use of distilled water is recommended when accurate results are to be aimed at.

For taking the surface temperature and specific gravity of the sea *vide* p. 54.

5. The **thermograph** is a self-recording thermometer and gives a continuous record of temperature. It should be exposed on deck in a louvred screen and its readings should be compared with the reading of the dry bulb thermometer at each time of observation.

6. The **psychrometer** measures the temperature and humidity of the air. Assmann's aspiration psychrometer consists of a wet and dry bulb thermometer placed side by side in metal tubes over which air is drawn by a quick-

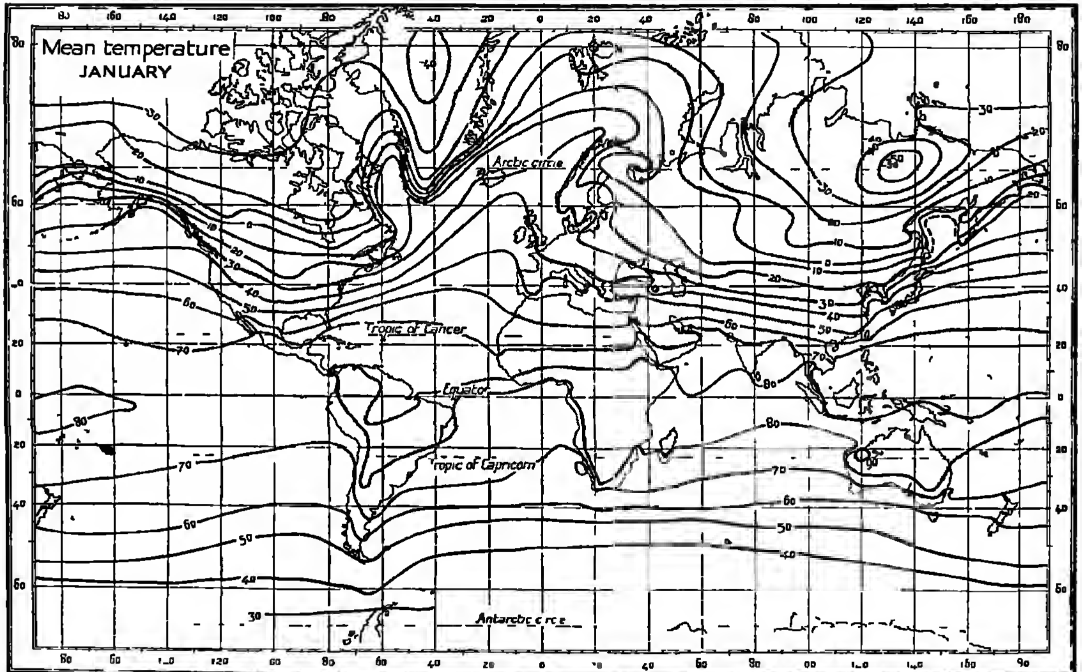
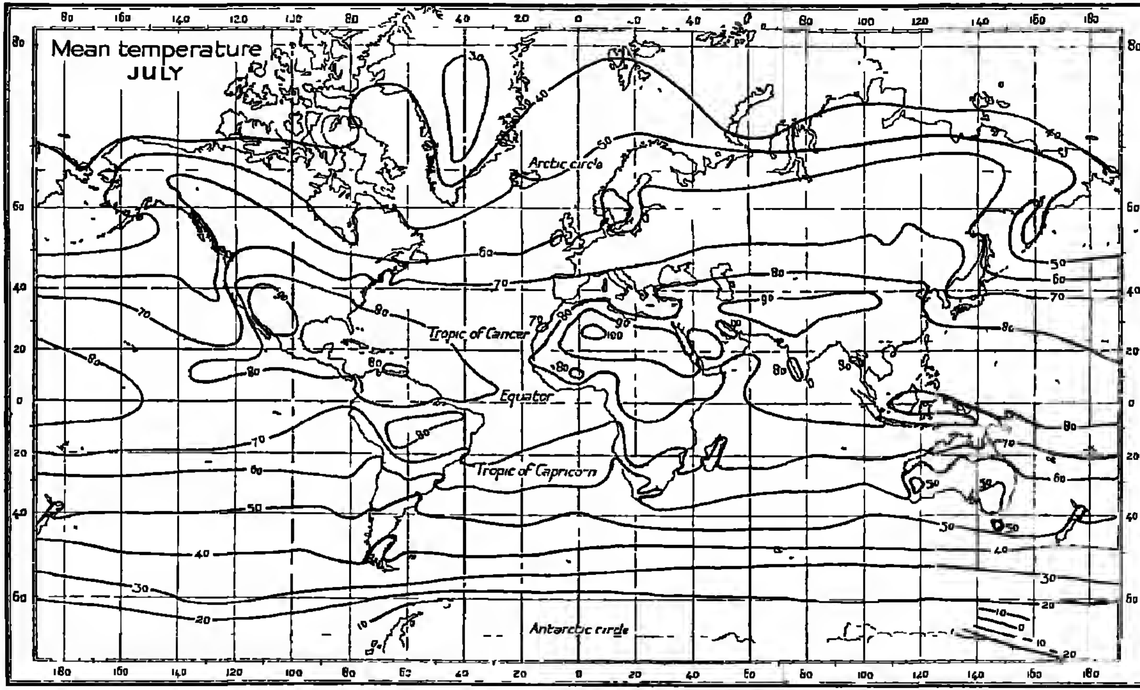

Mean temperature
JANUARY
Arctic circle
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic circle

Chart III

running fan actuated by clockwork. The Whirling Psychrometer consists of a wet and dry bulb mounted side by side on a boxwood frame. A spindle and handle are provided for whirling the instrument in the air. Observations with the psychrometer should be taken on the windward side of the deck over the ship's side.

7. The raingauge for use at sea is attached to an iron frame and is hoisted to a suitable height above the deck where it will be clear of the sheltering effects of deck houses, &c., and exempt from spray. Further observations of rainfall at sea are highly desirable as at present there are only a few observations available for comparison with the rainfall over the land. A number of ships have, however, in recent years been equipped with raingauges.

8. The anemometer registers the relative force of the wind. An electric cup anemometer is fitted in some ships. The cups turn a contact maker which completes the circuit and rings a bell once for every 25 turns of the cups. The interval between two rings corresponds with a wind run of 139 ft. The exposure of the anemometer is a very important point to be considered; when possible the foremast head is the most suitable position, the recording portion of the instrument being on the bridge. When, as is usually the case, there is no anemometer available the direction and force of the wind on the Beaufort Scale is obtained by observing the appearance of the sea and the effect of the wind on the surroundings generally. When there is a following wind and the smoke rises vertically, the speed of the ship gives the velocity of the wind. With winds in other directions the course and speed of the ship must be taken into account unless the estimation is made by observing the effect of the wind on the waves.



Mean temperature
JULY
Arctic circle
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic circle

CHART IV

The Circulation of the Atmosphere

The largest scale motion of the atmosphere is its rotation with the earth. At the equator, for example, the velocity due to rotation of any point on the earth is about 3 miles per second or over 1,000 miles per hour. In any other latitude the velocity due to rotation decreases in proportion to the cosine of the latitude, i.e. in proportion to the distance from the earth's axis. Thus the motion of the atmosphere due to its rotation with the earth is very much greater than the deviations from this value. What we generally call still air is air that is moving around with the same speed as the solid earth below it, and it is the deviation of the motion of air from the motion of the ground beneath it that we observe as wind.

We must not overlook this 'solid rotation' of the atmosphere with the earth. It is a motion which represents an enormous store of energy, and it is possible for a restricted region to draw upon this store of energy in the formation of a cyclone. In general, however, when we speak of air in motion we shall refer only to that motion relative to the earth which is known as wind.

We next have to consider the question 'Do the winds of the globe at any given time conform to some general scheme, at least so far as their main features are concerned?'. In other words, is there a general circulation of the atmosphere regarded as a whole?

We can most readily get at the answer to this question by considering for a moment the relation between wind and the distribution of pressure. This can be stated in the form known as Buys Ballot's law, which may be interpreted as follows: An observer who stands with his back to the wind has lower pressure to his left than to his right, or in other words an observer who faces into the

wind has lower pressure to his right than to his left. The advantage of adopting this rule at once is that we can reduce the question of the circulation of winds to that of patterns of pressure distributions.

The Charts I and II show the mean pressure distributions for January and July. It will be seen that in both these months there is at the equator a belt of relatively low pressure, and calm or light winds. There is a belt of calm around the greater part of the equator, known as the 'Doldrums', whose mean position is between 5° and 10° N. It swings to north and south of this mean position during the year, tending to follow the sun to north in the northern summer and to south in the northern winter.

Beyond the belt of calms, the wind blows from an easterly direction, with a component of motion into the belt of low pressure, so that the actual winds are north-east in the northern hemisphere, and south-east in the southern hemisphere. These winds circulate around the equatorial side of belts of high pressure (the sub-tropical highs), whose mean position in the southern hemisphere is centred about latitude 25°S. In the central region of the belts of high pressure winds are light, and these regions are known to sailors as the 'Horse Latitudes'. The wind circulation in the southern hemisphere is fairly regular and retains the same main features throughout the year. There the southerly side of the belt of high pressure is characterized by westerly winds, which cover a wide belt in which pressure decreases southward. In the northern hemisphere, however, the distribution of land affects very considerably the prevailing conditions. We have already referred to the influence of land and sea, and the tendency of high pressures to develop over the oceans in summer and over the continents in winter. We see from the January chart of mean pressure that while in the

northern hemisphere a narrow belt of relatively high pressure persists over the ocean, over North America there is an extensive region of high pressure, and over Asia there is a very large anticyclone which extends down into, and merges with, the sub-tropical high pressure. To the north of this arrangement of anticyclones and high pressure belts is a region of westerly winds and diminishing pressure, with well-marked low pressures over the North Pacific and North Atlantic. The low pressure region shown south of Greenland extends in a long trough across to the north of Scandinavia. North of this region pressure again increases and winds are easterly.

The above description of the mean pressure distribution and of the corresponding wind distribution gives a reasonably good picture of the day to day situation so far as the southern hemisphere is concerned, and also for low latitudes in the northern hemisphere. But over the North Atlantic the day to day variations are very considerable. This is a region of travelling cyclones and anticyclones at all times of the year. The cyclones of middle latitudes are usually centred near the boundary between the warm westerly current originating in low latitudes and the cold easterly current of polar latitudes.

During the northern summer the continental anticyclones of winter are replaced by vast regions of relatively low pressure, while high pressures develop over the oceans. The Atlantic anticyclone is on the average centred near the Azores, but it is subject to large oscillations of position. The Asiatic low pressure extends down over India to the Equator and over the eastern portions of Africa. Around the southern fringe of this region of low pressure a broad south-westerly current blows into the low pressure. This south-westerly current, which is called the 'South-west Monsoon', originates south of the Equator

and dominates the entire situation over the Indian Ocean. The belt of doldrums disappears over this region, being wiped out by the monsoon, which blows with considerable intensity, often attaining gale force in places. During this period the wind over the China sea is southerly, and that over the Mediterranean (the Etesian wind) is westerly, all in accordance with the pressure distribution, and all showing that the monsoon winds form part of the greatest cyclonic circulation of the globe.

What is known in the east as the north-east monsoon in winter is the trade wind, reinforced by the development of the Asiatic high pressure, but it never attains the strength of the south-west monsoon.

It is not possible to give an equally definite picture of motion in the upper air. The trade winds are reversed aloft, and a south-westerly wind blows above the north-east trade, and a north-westerly wind above the south-east trade. These currents form a part of the return flow from the equator.

The depressions and anticyclones of middle latitudes must not be regarded as mere incidents in the general circulation of the atmosphere. On the contrary, they form an integral part of that circulation, acting as means of transport of heat and momentum from equatorial to polar regions. They convey warm air from tropical or sub-tropical regions to higher latitudes, and cold air from high latitudes back to low latitudes. In midwinter when the sun is low even at noon, the temperature at places in middle and high latitudes depends far more on the direction of the wind than on whether the sun is shining. In December in England a cloudy day with a south-westerly wind is usually much warmer than a sunny day with a northerly wind.

The Upper Air

While meteorology has made great strides since the days of Maury, we are still far from having arrived at a complete understanding of the physical processes at work in the atmosphere, and there are many types of observations which are to-day urgently needed to help in solving some of the problems of the atmosphere. First among these comes the observation of upper winds and temperatures.

Our knowledge of atmospheric conditions over the land has been greatly extended in recent years and systematic observation of upper winds up to considerable heights above the ground are carried out in most of the principal countries of the world, but there still remains the sea area amounting to $\frac{4}{5}$ths of the globe over which comparatively few observations have been recorded.

From the information obtained over the land we can say that in general the wind veers and increases in strength up to about 1,500 feet, above this it may still increase with height but follows no general rule, and its variation will be mainly controlled by the distribution of temperature in the horizontal. The variations of wind with height are much less regular than the variation of temperature with height. The latter can be estimated with considerable accuracy and on the average falls off 1°F. for every 300 feet in all latitudes.

Observation of winds and temperatures in the upper air over the sea are urgently required and the co-operation of those who go down to the sea in ships is necessary in order to obtain them.

Two forms of observation have been proved to be practicable at sea.

(1) The observation of a track of a pilot balloon by means of a sextant and compass. The balloon is of india-

rubber and inflated with hydrogen and released from the ship. Its rate of ascent depends upon its weight and free lift; a usual rate of ascent is 700 feet per minute, so its height can be found approximately at any time by noting the number of minutes that have elapsed since the time of starting. The altitude and azimuth are obtained by means of a sextant and compass, and from data so obtained the velocity and direction of the horizontal current are found at any time.

(2) The other form of observation is by sounding balloons. These balloons are of larger size than those which are used as pilots. They are sent up in pairs in tandem and carry a sea anchor float and a self-recording instrument, known as a meteorograph, which records simultaneously the pressure, temperature, and sometimes also the humidity. The height at any moment is deduced from the observations of pressure and temperature. On attaining a great height, say 40,000 or 50,000 feet, one of the balloons will burst and the remaining balloon, being unable to support the instrument, descends until the sea anchor float reaches the water. The balloon is now able to support the instrument some feet above the surface of the water and is prevented from drifting by the sea anchor float until recovered by the ship which has followed it. The balloons take about an hour to go up and an hour to come down.

If the sea room is limited or if time is not available for taking observations up to the maximum height, a device can be attached by which the upper balloon can be released at a pre-arranged height. The device consists of an aneroid box which expands as the pressure on it decreases and by so doing releases a catch which holds the upper balloon. A sketch of the apparatus after release is given in Fig. 6.

In cases where the pilot balloon method is not practicable, observations of the motion of cloud are still useful. It would be of great assistance to have observations of cloud anywhere near a tropical cyclone, as these might help to throw light on the origin of the cyclone.

Weather Charts

The modern method of forecasting weather is based on the use of a synoptic chart, i.e. a chart on which are plotted a number of observations all taken at the same time over a wide area. The observations show the actual barometric pressure, direction and force of the wind, temperature, weather, &c., at the time for which the chart is compiled. Lines are drawn through the places where the pressure is the same and are known as 'isobars'. The isobars are the most important feature of the chart and give a pictorial representation of the pressure distribution at sea level. The wind always takes a definite direction relative to the trend of these lines and its velocity is approximately inversely proportional to their distance apart.

If the isobars are drawn over a large area in middle latitudes, it will be found generally that some of the isobars are closed, and run round a centre of low pressure, like the contour lines of a hollow on a map, while others run round a centre of high pressure like the contour lines of a hill on a map. These two types of pressure distribution are called a depression and an anticyclone, or 'low' and 'high', respectively. Regions on a synoptic chart are usually classed as one of seven types, but the seven types are in reality included in the depression or anticyclone, or in the regions between pairs of these. It has been found that certain definite distributions of weather are associated with each particular type of pressure distribution. A full

FIG. 6. Sounding Balloon as used in meteorological work

description of these types will be found in any text-book of meteorology.

The aim of drawing synoptic charts at sea is to make it possible to forecast the weather for some time in advance. The central problem of weather forecasting may be stated in a few words. It is the problem of forecasting the changes in the pressure distribution, since the winds and weather are associated very closely with the pressure distribution. And further, since the changes in pressure distribution in middle latitudes are mainly brought about by the motion of depressions, the main problem of the forecaster is to determine the future motion of the depressions, which appear or are likely to appear on the chart.

Chart V shows a synoptic chart drawn at sea from information obtained by wireless telegraphy from shore stations and ships. The direction of the wind is represented by an arrow flying with the wind, the point of the arrow being on the position of the station, the force of wind is represented on the Beaufort Scale by the number of flèches on the arrow. The pressure is given in millibars[1] and inserted alongside the point of the arrow. The air temperature is in degrees Fahrenheit and is noted below the pressure. Sea temperature is given in degrees Fahrenheit in brackets alongside the air temperature. The weather in letters of the Beaufort notation is given below the figures for temperature. The figure above the pressure indicates the number of half-millibars the pressure has changed during the last three hours, indicating the rise or fall of pressure. Weather messages giving synoptic data are issued from stations in all parts of the world and in addition a certain number of Atlantic liners send regular reports to the London Meteorological Office. These messages which are usually in code (see Admiralty List of

[1] 1,000 millibars = 29·53 in.

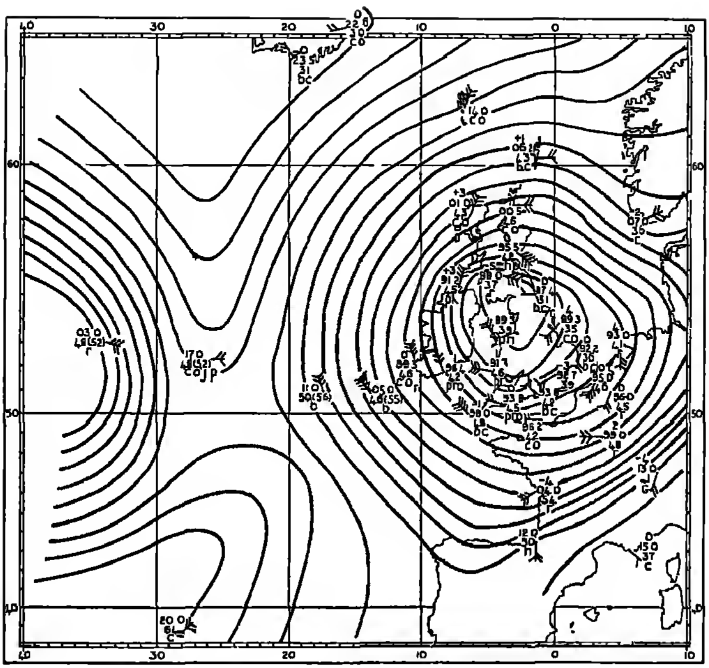


CHART V

W/T Signals) can be intercepted with a wireless set by any one requiring them.

Full instructions for drawing synoptic charts are given in 'Forecasting Weather' by Sir Napier Shaw and other Meteorological publications.

Some Phenomena observed at Sea

The tropical cyclone. This is the revolving circular storm of low latitudes, whose name varies with locality. It is known as a cyclone in the Indian Ocean and Mozambique Channel, as a hurricane in the West Indies, and as a typhoon in the China Seas. Its area is small, but within that area pressure falls off very steeply towards the centre, and the winds which occur in it are extremely violent. Its motion is so slow, that when a falling barometer has indicated the approach of such a storm, by taking note of the 'Law of Storms' it should be possible to navigate the ship away from the centre.[1]

The central region of the tropical cyclone is a region of calm, often giving a glimpse of blue sky. The approach of the cyclone is usually heralded by motion of cirrus away from the centre.

The **tornado** is similar in its nature to the tropical cyclone. It is, however, of much more limited horizontal extent, but is capable of doing immense damage on account of the colossally high winds it produces. Tornadoes frequently appear to form at the boundary of two opposing currents, much after the manner in which eddies form as dimples in a mill pond at the boundaries of an inflowing stream of water. It is, however, certain that tornadoes can be formed by violent convection of heated air. Many were observed to form over the fires which devastated Tokyo after the great earthquake of September 2, 1923, and a

[1] *Vide* Barometer Manual, 1925 edition, p. 76.

vivid description of the formation over a great fire of oil of a succession of whirls, one of which carried a cottage some fifty yards and then dropped it as a complete wreck, will be found in the 'Scientific American' for December, 1926.

The **waterspout** is a small tornado over the sea. The whirl is supposed to be set in motion by the interaction of opposing currents. The whirling motion leads to a diminution of pressure within the core, with a consequent lowering of temperature. If the temperature falls below the dew point, condensation takes place and the core is made visible by the water drops. It frequently happens that the core is visible below a cloud, and again at the sea level, but invisible at middle heights. The reason for this is the relative dryness of air at middle heights in contrast with the nearer approach to saturation of air near cloud level and above the sea. There may be a certain amount of sucking up into the core of water drops churned up from the sea surface. The winds in the whirl are extremely violent, but the horizontal extent of the whirl is very slight and usually no effect is observed at 100 yards from the centre. Waterspouts frequently occur in groups of two or three or more.

Land and sea breezes occur over most coasts, though they are frequently masked by other conditions. The sea breeze, blowing towards the land, sets in during the morning, and the land breeze, blowing towards the sea, sets in during the evening. Along tropical coasts, the sea breeze prevails during the greater part of the day, reaching its maximum intensity about 2 p.m., and the land breeze prevails during the greater part of the night, reaching its maximum intensity about 1 a.m. These winds are shallow, extending only to a height of 500 to 1,000 feet, where they die away, and are presumably replaced by a return

current. The direction of motion at the surface is always from cold to warm, i.e. from cold sea to warmer land by day, and from cold land to warmer sea at night.

Clouds may be observed to perfection at sea, where the whole sky is visible down to the horizon. The very large number of forms of clouds may be divided into four main classes, cirrus, cumulus, stratus, and nimbus, following the classification proposed by Luke Howard at the beginning of the nineteenth century. Cirrus clouds are very high clouds of feathery or wisp form. Cumulus clouds or heap clouds may occur at almost any height from 1,000 to 10,000 feet. Stratus cloud is a flat cloud sheet or layer in appearance like a high fog. Nimbus cloud is the heavy rain cloud. For our present purpose this classification is sufficient, but it may be added that intermediate types occur between these main classes. An international classification of clouds is described in a small pamphlet published by the Meteorological Office, entitled 'Cloud Forms according to the International Classification'. In this pamphlet twelve types of cloud are described.

The observation of clouds is the first step in the study of meteorology. Cirrus clouds moving from the centre give the first indication of the approach of the depressions of middle latitudes, as well as of the approach of the tropical revolving storm. Cirrus clouds are frequently to be observed above the north-east trades, moving north-eastward in a south-westerly current. Cumulus clouds predominate in the doldrums and in the south-east trade belt.

Rainfall. Observations of rainfall at sea are unfortunately few, largely on account of the fact that its measurement is not quite so simple as on land since it necessitates a special raingauge equipment. Much valuable information could be obtained even without a rain-

gauge if the time when the rain began and ceased were recorded in the log, with a descriptive note as to whether the fall was light, heavy, or torrential.

Fog is caused in general by the cooling of damp air until condensation takes place. On land this happens most frequently through the cooling of the ground by radiation at night, but that cause is not effective at sea to an appreciable extent. A more potent cause of fog at sea is the passage of a warm damp current of air over cold sea. Much of the fog of the Great Banks of Newfoundland occurs in currents of air which first traverse long distances over warm sea, thereby becoming warm and damp, afterwards reaching the cold currents of sea off the Great Banks, where they are cooled from below by the cold sea surface. Sea fogs are generally formed in this way, by the passage of warm damp air over colder water. For this reason they are more prevalent in summer than in winter. Land fogs which are mostly associated with winter anticyclonic conditions may drift out over the sea, as frequently happens around the coasts of the British Isles in autumn and winter. True sea fogs, formed over the sea, are more frequent in summer than in winter. Coastal fogs may partake of the nature of either land fog or sea fog. There is apparently another class of sea fog, formed when cold air passes over a warmer sea. The physical conditions of the formation of fog in these cases is not clear. Probably a layer of warm saturated air is formed near the sea surface, and the mixing of this layer with the lowest layers of the cold air produces fog.

Coastal fog may be expected whenever there is a change of wind current, whether it be the replacement of a cold current by a warm current, or vice versa.

When an unusual phenomenon is observed, it is important to give as full details as possible of all the

conditions prevailing at the time. Thus observation of fog may be usefully accompanied by observations of sea and air temperature, and a note should always be made of the depth of fog when this can be observed.

Now that wireless telegraphy has become universal, observations of sudden occurrence, or sudden cessation, of atmospherics, may well lead to increased knowledge in unexpected ways. Changes in ease of wireless reception with the approach or receding of a tropical cyclone are of interest, since it has been stated by certain writers that atmospherics are always associated with the clash of warm and cold currents. This view is not given as correct or incorrect, but is stated merely in order to show that if no atmospherics are observed in a tropical cyclone, then on that view, the tropical cyclone is made up of warm air, and is not due to the interaction of warm and cold currents. Observations of atmospherics may therefore be of great value in meteorology.

Optical Phenomena. There are innumerable opportunities at sea for the observation of optical phenomena. Such phenomena, being of only occasional occurrence, should always be carefully observed and recorded, not only because they often give the first indication of an approaching storm, but because of their intrinsic interest.

Among the optical phenomena most frequently observed at sea we may include rainbows, coloured rings round the sun and moon (known as coronae, halos, &c.), sun pillars and the green ray. The sun shining on the drops of water in a passing shower produces the **rainbow** by double internal reflection. Frequently a second and even a third rainbow may be seen concentric with the first, but much fainter than the primary. When an observer stands facing a rainbow he has the sun behind him.

Rainbows are frequently to be seen at night, when the moon is bright.

Coronae are rings of coloured light seen around the sun or moon when shining through clouds of the cumulus or stratus variety. Halos are due to sunlight or moonlight shining through high clouds of cirro-stratus, in which ice crystals take the place of waterdrops. Halos present very striking and beautiful effects, sometimes of a very complex form. Careful observation should be made of all such phenomena, which are of considerable intrinsic interest. The observations should include the height of sun or moon above the horizon, the state of the sky as regards clouds, the hour of the day, the diameter of the main ring measured by a sextant, and the diameters of any fragmentary circles estimated by their visible arcs.

A **sun pillar** is a pillar of light which, as the sun sets, shoots vertically upward through a height of 10 to 15 degrees above the point of setting of the sun. It usually remains stationary for some time.

The **green ray** at sunset and sunrise is the brilliant green colour which the line bounding the upper limb of the sun assumes when it is just touching the water horizon. This phenomenon is plainly visible to the naked eye, but the old navigators do not appear to have noticed it.

Electrical Phenomena. Amongst the electrical phenomena we have—apart from lightning—the aurorae and St. Elmo's fires. At times the aurora appears as pulsating waves of white light, flashing across the sky in independent action. An aurora is generally white, but the display is often accompanied by a decidedly red appearance of the sky. St. Elmo's fire, which appears as a sort of electrical discharge, occurs in the height of storms, not always thunderstorms. These fires indicate a highly electrical state of the atmosphere, the light seeming to

play round the mastheads and yards of a ship with a faintly white glow. It would be worth noticing whether the steel masts of a steel ship with wire rigging would show this effecr.

Finally, it is extremely desirable that any one aspiring to make observations of value in marine meteorology should consult the instructions issued by the Meteorological Office and such standard works as are cited in the List of Literature given on p. 483.

II

THE WATER

BY D. J. MATTHEWS

Our knowledge of the physical geography of the sea, of its depths, composition and temperature, and the direction and speed of its movements, has been derived almost entirely from observations made from ships at the surface. Surface observations are made directly with simple apparatus, but observations in the depths must be made by means of apparatus which can be lowered to the required level on a line of known length.

A complete set of physical observations at any position would include the following at least:

1. Position, date, and time.
2. Depth.
3. Nature of the bottom.
4. Temperature at surface, intermediate depths, and bottom.
5. Collection of samples of water, as in 4, for the determination of:
    - *a*. Salinity.
    - *b*. Specific gravity.
    - *c*. Dissolved gases.
    - *d*. Other minute constituents such as phosphates, silicates, arsenites, nitrates, nitrites, ammonia, &c.
    - *e*. The hydrogen ion concentration (*p*H).
    - *f*. Any other special objects of investigation.
6. Currents at as many depths as possible.
7. Transparency, or depth to which light can penetrate.
8. Colour.

The list is a formidable one and only a large staff in a well-equipped ship could hope to deal with it. But it must not be supposed that if many of the observations are omitted the others are of no value. The position, date, and time, must of course be given. But a yachtsman provided with the gear necessary for determining temperature and collecting samples of water down to a depth of a few hundred fathoms need not hesitate to use it because he cannot measure the currents or make a sounding in the two or three thousand fathoms of water which may lie beneath his keel. Even surface observations alone are of value, especially in little frequented waters.

History

The serious study of physical oceanography may be said to have had its origin in the work of Maury. He extracted from ships' logs the scattered observations of winds, currents, temperatures, and so forth, and published the results in charts of mean values. It was found that the use of these charts by navigators led to such a marked shortening of passages that the collection of data was organized and now many hundreds of vessels make regular returns of observations to national institutions such as the Meteorological Office and the German Seewarte. The next great impetus was received when deep-sea cables raised for repair were found to be encrusted with living animals, and the belief that the depths of the oceans were lifeless wastes, or at least inhabited only by the lowest forms, was disposed of for good and all. Following on this discovery many expeditions were fitted out for the study of oceanography, the most famous of which was that in the *Challenger*. Since that date many research ships have been sent to sea, some for pure oceanographical investigation, some chiefly as surveying ships, and some

for polar exploration in the first place. At the beginning of this century the International Council for the Exploration of the Sea was instituted, with its head-quarters at Copenhagen. Though founded primarily to study the fisheries of northern Europe it has conferred the greatest possible benefit on physical oceanography by drawing up tables showing the relation between chemical constitution, salinity, pressure, temperature, and density, and by providing tubes of 'normal water', that is, carefully analysed seawater, to be used as standards in the determination of salinity. The work of the Council led to detailed study of the conditions in the fishing-grounds and their variations, both periodic and unperiodic, and has provided a model for such work elsewhere. At the time at which this is being written great advances are being made in physical oceanography, so great indeed as to lead to a faint regret that a revised edition of this book must be prepared just now. The oceanographical work of the *Gauss* expedition in the southern Indian and the Antarctic Oceans and of the *Sealark* in the Indian Ocean proper has just been published; two great expeditions have recently returned from the South Atlantic Ocean in the *Discovery* and the *Meteor*, and the detailed investigation of the Pacific Ocean is being taken in hand by the Pan-Pacific Conference. In one direction, however, it is to be feared that oceanography will suffer. The success of the echo-sounding gear makes it not unlikely that nearly all deep soundings will be made with it in the future, with a consequent serious decrease in the number of bottom temperatures and of specimens of bottom deposit collected.

The Temperature and Salinity at the Surface

We must first consider, in the broadest outlines only, what is known of the general distribution of temperature, salinity, and currents, for these are the foundations of oceanographical investigation. Only two assumptions need be made for the present; one, that sea water is pure water in which is dissolved more or less of a mixture of constant composition, over three-quarters of which is common salt, sodium chloride; and the second, that the density of sea-water increases as the salinity and pressure rise and the temperature falls.

The average distribution of surface temperature is shown on Chart VI, which is founded chiefly on data contained in the meteorological logs kept in ships for the national institutions in various countries. In areas far from the traffic lanes records are naturally scanty and here the yachtsman can do valuable work. The chief points to be noticed are the broad belts of maximum temperature crossing each ocean between the tropics, in which there is little change in a north and south direction, the more rapid fall polewards outside the tropics shown by the crowding of the isotherms (lines of equal temperature), and the irregular course of many of the latter. If the temperature of the sea depended upon the altitude of the sun we should expect the isotherms to be parallel to the equator, but actually they often follow a very different course. The isotherm for 5° C. for instance in the North Atlantic runs for a space nearly north and south off the coasts of Labrador and Newfoundland, and that for 10° C., from about 40° N. lat. on the Atlantic coast of North America to nearly 60° N. lat. off the west of Scotland, a difference of latitude of nearly 1,200 sea miles. These irregularities are due to the Gulf Stream [1] (Chart VII),

[1] Or North Atlantic Drift (see p. 51).

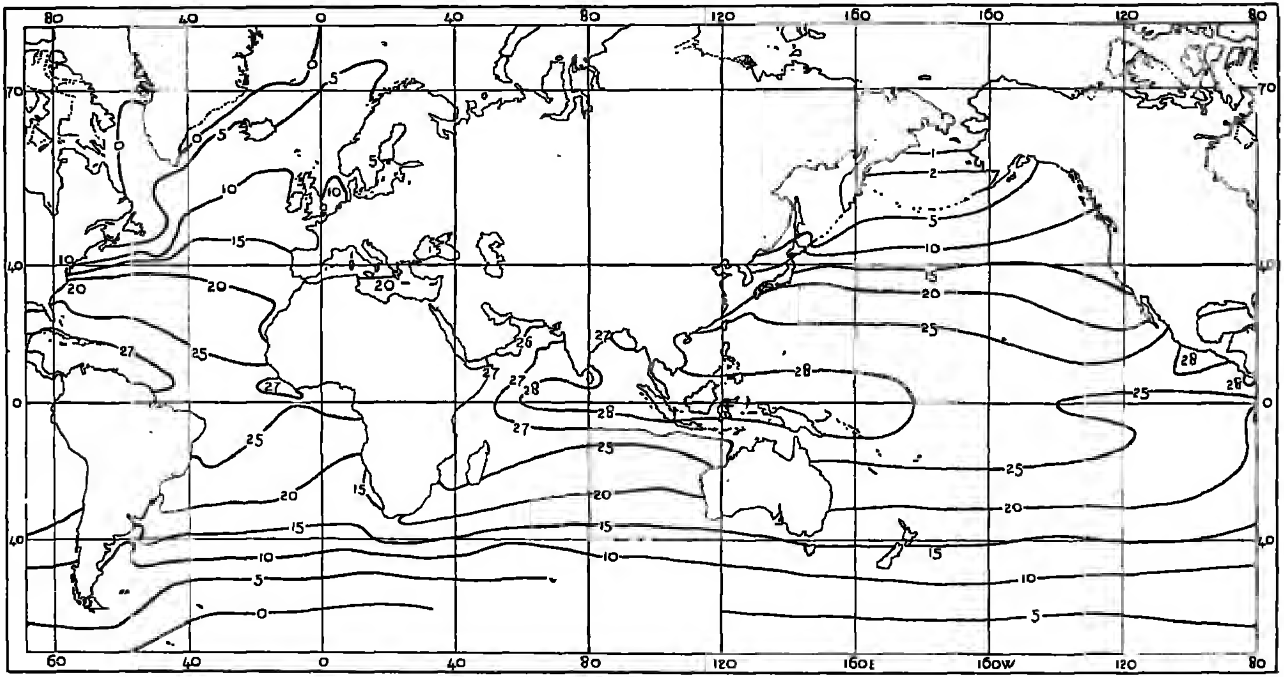


Chart VI

The mean surface isotherms (Centigrade). The lines are drawn through points of equal temperature

which carries tropical water to the British Isles, the coasts of Norway, and even to Spitzbergen, and to the Labrador Current, which brings southward ice-cold water, with bergs and pack ice during the early part of the year. The warm water loses a great deal of its heat on its long drift, but still retains enough to keep the Norwegian harbours always free from ice and make Spitzbergen approachable on its western side during the summer months. Much of the heat lost in the Norwegian Sea is carried to Norway by the prevailing on-shore winds and gives it a comparatively open climate; without these winds the warm waters would have little influence except on a narrow strip along the coasts. In the South Atlantic Ocean the Brazil Current and the Falkland Island Current are the causes of the sharp bends in isotherms between 25° C. and 10° C. on the American coast. Off the Japanese coasts the warm Kuro-siwo, the counterpart of the Gulf Stream, gives rise to similar irregularities but on a far smaller scale. The average minimum temperature of sea water is its freezing-point, between −1° C. and −2° C., but there is no natural upper limit. In the open sea temperatures above 28° C. are uncommon, but very high readings have been obtained in the enclosed waters of the Persian Gulf, reaching even 35° C., nearly the temperature of the human body.

The distribution of surface salinity (Chart VIII) is less simple than that of temperature. The average salinity of all the oceans is about 35 parts per thousand by weight. The upper limit of over 40 per thousand is reached in the northern part of the Red Sea, where the evaporation is intense and the inflow of fresh water negligible. Salinities of 39 per thousand are found in the neighbouring waters of the eastern Mediterranean. In the open oceans the highest salinities occur near the centres of high barometric pressure, where rapid evaporation occurs under

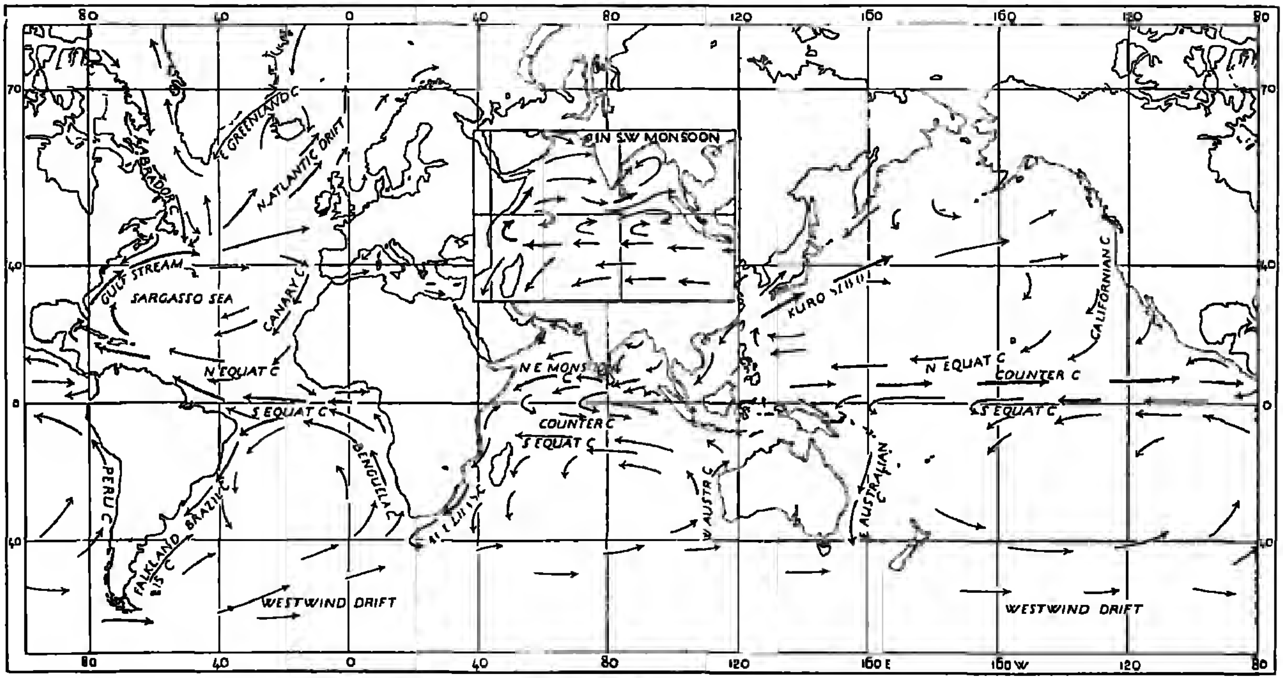


CHART VII

The mean surface currents

clear skies with nearly constant breezes and only weak surface currents. The most famous of these is in the centre of the North Atlantic Current whirl, the Sargasso Sea, with a salinity reaching nearly 38 per thousand. Similar centres occur in the South Atlantic, in the Pacific, and in the Southern Indian Oceans. In the Northern Indian Ocean the conditions are somewhat different because it is barred by land north of 20° N. lat., but a large area of high salinity occurs in the Arabian Sea. The effect of the great surface currents on the distribution of salinity is as clear as in the case of temperature. The Gulf Stream and North Atlantic Drift carry great masses of water of 35 per thousand salinity to Norway and Spitzbergen, and near this the East Greenland Current brings southward water from the Polar Sea, the salinity of which has been reduced to 32 or less by the outflow from the great rivers which enter it and by snowfall and the melting of ice. Heavy rain and large supplies of river water are also found in low latitudes, and salinities of less than 34 per thousand occur near the equator in the open sea, but here they are associated with high temperatures.

It is difficult to assign a lower limit to the salinity of true ocean water: perhaps it may be put conveniently at about 32 per thousand. In enclosed seas it may be much less, and in the Gulf of Bothnia the water is almost drinkable.

There is another factor affecting surface conditions of which mention must be made; that is upwelling from below. Where an off-shore wind or even a wind along the shore removes the surface water more quickly than it can be replaced by surface flow, water wells up from below and marks its presence by relatively low temperatures. Such areas of upwelling occur in many places, such as off the Atlantic coast of Morocco, in Walvis Bay, in the waters north of Sokotra, under the lee of the Galapagos

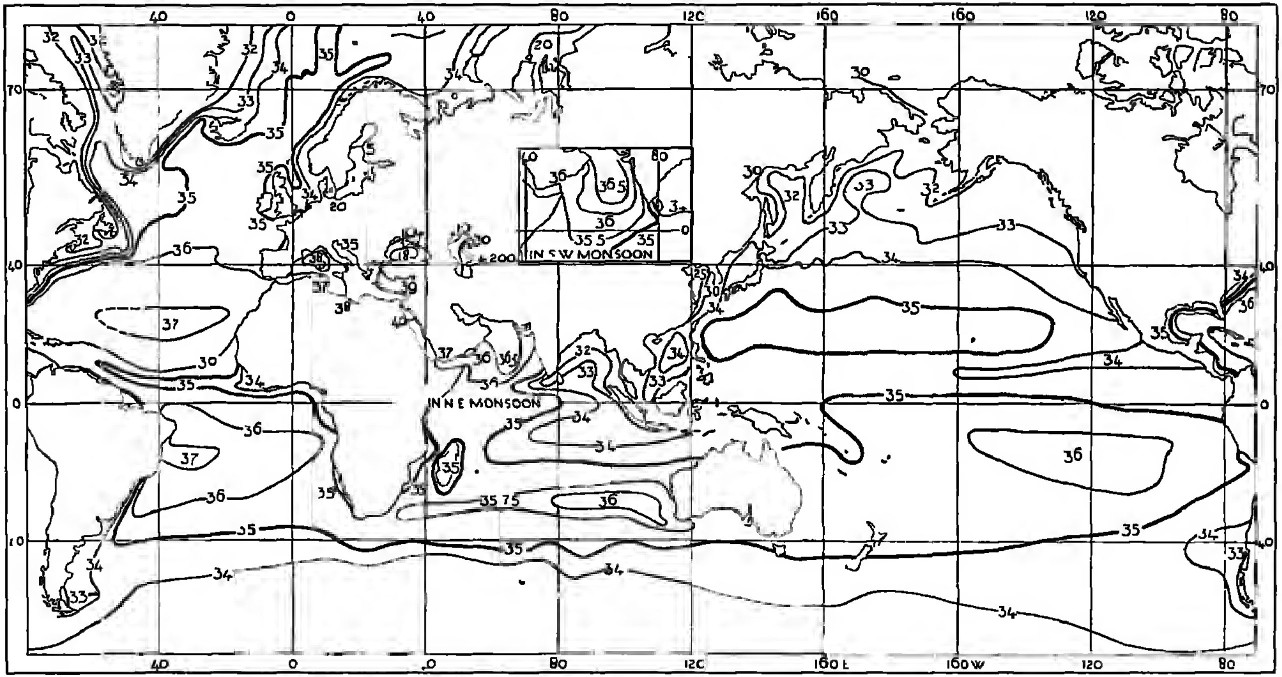


CHART VIII

The mean surface isohalines, showing the weight of salt in parts per thousand after Schott

Islands, and in the Peru or Humboldt Current on the western coast of South America. Part of the low temperature of the latter is due to its origin in the cold easterly drift of the Southern Ocean, but its extraordinary uniformity over many degrees of latitude is almost certainly caused by its origin in a deep layer the temperature of which hardly changes with increase of distance from the Antarctic Continent.

Seasonal Changes in Temperature

The seasonal change of surface temperature varies greatly from place to place. There is, for instance, a small area in about 5° N. lat. in the North Atlantic Ocean where the mean yearly range is less than 1° C., and a large one on both sides of the equator in which it is only 2° C.; such a condition is easily explained by the facts that the midday sun is never low and that the meteorological conditions are fairly constant. South of Newfoundland the mean range is 15° C. or more, owing to the variation in the layer of cold low salinity water from the Labrador Current and from the St. Lawrence River, combined with the greater change in the altitude of the sun. The seasonal changes of salinity are also considerable, and due largely to changes in the strength of currents and in the outflow from rivers.

The seasonal change decreases with the depth and is very small below 200 m.; it can be detected in still greater depths, but it is difficult to decide how much is due to a change proceeding downwards from the surface and how much to variation in the strength of deep currents.

An important result of the decrease of seasonal variation downwards is that observations at depths of 400 m. or more may be used for drawing charts and sections of temperature and salinity, regardless in most places of the time of the year at which they are made.

The Subsurface Circulation of the Oceans

It has long been known that in the open sea both temperature and salinity decrease continuously, on the whole, with increase of depth. On the bottom, in depths greater than 1,000 m., the salinity is not far from 35 per thousand and the temperature 3° C. or less, falling to below 1° C. in some areas in free communication with high southern latitudes. It has also long been known that the rate of decrease varies from place to place. In the Sargasso Sea, for instance, water of high salinity and temperature penetrates to great depths, in the corresponding southern latitudes to depths which though smaller are still considerable, while under the equator relatively cold and fresh water rises to near the surface. A very simple theory of the deep circulation was founded on these observations. It was supposed that the surface water of subtropical and temperate zones sinks to moderate depths in both northern and southern hemispheres, and then turns towards the equator, where it rises to replace the water carried away by the surface equatorial currents. According to the theory it receives at the same time a considerable addition of very cold water which has sunk from the surface in high latitudes and has made its way equatorwards along the bottom; the mixture of these two waters accounts for the low temperatures at small depths under the equator. This theory divides the deep circulation into two nearly symmetrical parts.

More recent observations and the rediscussion of the older ones have shown that the true circulation is probably far more complicated. In the Atlantic Ocean, for instance, there appear to be at least four different layers of water. In the equatorial regions there is first the surface layer of a depth of a few hundred metres only.

Below it, from about 500 m. to 1,200 m , there is a layer of lower salinity which has been formed along the shore of the Antarctic Continent and spread northwards to 45° or 50° S. lat., where it has sunk and continued its way to at least 15° N. lat. Below this again there is an increase of salinity due to a current which has sunk from the surface in the subtropical waters of the North Atlantic Ocean and flows southwards to 50° or 60° S. lat., where it rises a little and appears to mix partly with the current of low salinity going northwards and partly with cold and dense water which sinks along the edge of the continent and covers the larger part of the bottom of the Atlantic Ocean. The differences of temperature and salinity on which this theory of the deep circulation is founded are comparatively small and demand the most accurate thermometers and water-bottles for their observation. It would be advisable too in the future to space the observations below 1,000 m. somewhat more closely than has been usual in the past. The maximum–minimum thermometer is of course useless under such conditions, unless it is so slow that it can be lowered through layers of considerable thickness without taking their temperature, as appears to have been the case with those used in the *Challenger*. But a slow thermometer leads to great uncertainty and to loss of time.

The complete truth of this theory of oceanic circulation cannot be said to have been proved as yet, largely because the question of currents in other than meridional directions has not been sufficiently considered, but it fits the facts as known at present better than any other, and the recently published observations in the southern Indian Ocean provide additional support. The investigations of the South Atlantic Ocean now in progress should show decisively whether the theory is tenable or not.

The circulation in the Indian Ocean appears to be

identical if allowance is made for its limitation in a northerly direction, and the circulation of the Pacific Ocean is probably on the same model.

The Faroe-Shetland Channel

The Norwegian Sea and Arctic Ocean are cut off from the North Atlantic Ocean by a rise stretching from the north of Scotland to the Faroe Islands, Iceland, and Greenland, with a maximum depth of about 600 m. The part of the rise which lies between the Faroe and the Shetland Islands has a maximum depth of not quite 500 m. and a width of about 12 miles; the Faroe-Shetland Channel which crosses it is the most famous region in the history of oceanography. On the south side we have the warm water of the North Atlantic Drift (Gulf Stream Drift), with nearly uniform temperature of 7° C. or more and a salinity of 35·3 per thousand down to a depth of 1,000 m., and on the north side the cold arctic water, with a temperature only a little above 0° C. and a salinity of 34·94 per thousand. The Drift water streams through this Channel, which it fills nearly completely and covers the southern Norwegian Sea with warm water to a depth of 400 m. or more. A little of the cold northern water flows southwards over the ridge on the bottom, but its amount is insignificant. Thus there is one continuous body of water from the surface down to the level of the Ridge, while below this level there are within a few miles of one another two perfectly distinct water masses each with its peculiar temperature, salinity, and animal life.

Conditions in Enclosed Seas

Many enclosed seas are connected with the oceans or with the larger seas by narrow entrances nearly blocked by relatively shallow bars, so that they are completely cut

off from the cold bottom waters which are formed in high latitudes. Such seas will be filled from the depth of the bar down to the bottom with the densest water which can gain access to them. At most places, but not everywhere, the temperature is the decisive factor and the densest water is the coldest; the temperatures in such seas will depend upon that in the outer ocean at the greatest depth over the bar, the 'threshold depth', and upon the average minimum surface temperature. In the Sulu Sea the threshold depth is 700 m. and the temperature of the Pacific Ocean at this depth is 10·2° C., while the minimum surface temperature is much higher. The densest water which can gain access to the sea is that of the outer ocean at 700 m., and accordingly the temperature from this depth to the bottom in more than 4,000 m. is 10·2° C.

In the Mediterranean Sea the mean minimum surface temperature in the winter is between 12° C. and 13° C., and this extends to all depths. The water is therefore slightly warmer than that of the Atlantic Ocean at the 'threshold depth', but at the same time it has been so concentrated by evaporation, to a salinity of 38 per thousand or more, that it is the densest water of the region. Accordingly it fills the Mediterranean from two or three hundred metres downwards and flows out as a bottom current over the Gibraltar rise, while on the surface the Atlantic water flows in to take its place.

As a third example of an enclosed sea we may take the Black Sea, which is connected with the sea of Marmora by the Bosporus, with a minimum depth of a little under 50 m. It is divided into an upper layer of about 200 m. in thickness in which the salinity is reduced to 18 per thousand by dilution with river water, and a lower layer from 200 m. to the bottom, the water of which is derived from the Sea of Marmora and has a salinity reaching 22 to 23

per thousand at 2,000 m. with a temperature of about 9° C. Owing to the great differences of salinity, the surface water, however much it may be cooled, can never become heavy enough to sink through the bottom layer, and vertical circulation stops at 200 m., with the result that the minimum temperature occurs at a depth which varies with the position from 50 m. to about 100 m. An even more striking result of the cessation of convection at 200 m. is that below this depth all the higher forms of life are missing owing to the lack of oxygen, and the water smells of sulphuretted hydrogen set free by the action of bacteria upon the sulphates present in solution.

Finally, we may refer to a peculiar kind of enclosed sea which is found in its most striking form in the Western Pacific Ocean. Such seas are deep steep-sided depressions in a relatively level ocean floor with free access to the cold bottom water. This bottom water as it sinks into them is heated by compression so that the temperature increases downwards.

Ocean Currents and their Causes

i. External Causes

The chief cause of ocean currents is the direct friction of the wind upon the surface of the sea. In proof of this we have the experience of all seafarers, the agreement between the charts showing the permanent wind systems and the permanent currents, and the result of direct observations of the effect of local winds of short duration. These observations have been made in various places, and the experiments carried out in the Baltic in lightships are probably the most satisfactory because they are practically unaffected by tides and because care was taken to measure the speed a short distance below the surface in

order to avoid the direct action of the wind on surface drifters.

In comparing the directions of the currents with those of the winds which gave rise to them, it must be remembered that the rotation of the earth causes every moving body on its surface to drift 'with the sun' if it is not prevented from doing so by other forces, so that a current tends to deviate to the right of its path in the northern hemisphere and to the left of it in the southern. And this is not a purely theoretical deduction. The charts of the permanent systems show it, and in the Baltic deviations to the right of the wind are more frequent than those to the left. Further, the surface current must act like a wind on the layer immediately beneath it, which is in turn set in motion with a further deflection *cum sole*, with the sun, and at a slower speed. It is plain that at a certain depth the direction of the current must be reversed and its speed very small. The depth at which this occurs cannot be calculated because we do not know the magnitude of the friction due to eddies between the moving layers, but actual observation has shown that the depth of a great wind drift in the open sea where it is not constrained by the neighbourhood of land is surprisingly small, perhaps 100 to 150 metres (50 to 80 fathoms), and the reversal of direction must take place at some depth not very different from this. On the other hand there is reason to believe that where the current as it swings round is banked up against other bodies of water its movements may extend to much greater depths. It is often stated that the rotation of the earth can set up a current, but this is a fallacy. The rotation can only influence a body already in motion, and the magnitude of the deflecting force is directly proportional to the velocity: when velocity is nil there is no deflection. If rotation could set up a current it

would be impossible for a sphere to remain motionless upon a level surface in the absence of some other force constraining it to do so.

An important consequence of this deflection is that an ocean current in the open sea has little momentum; as soon as the driving force is removed it swings from its path and tends to return on its tracks.

It is also often stated that the areas of permanent or semi-permanent high barometric pressure can cause permanent currents. If this were so the sea bottom should be dry beneath these 'highs' as a result of currents flowing away from them for long ages. What really happens is this. A sudden increase of barometric pressure sets up a current beneath it which carries water away until the surface has been lowered by an amount corresponding to this pressure. Suppose, for instance, that the barometer suddenly rises by one inch; mercury is about 13·6 times as heavy as water, so the current will continue until the level of the sea has been lowered by 13·6 inches and then cease. Observations on the question are difficult to make because it happens that in the localities otherwise suitable for the purpose a change in barometric pressure sets up winds which also give rise to currents and it is not easy to separate the two effects.

ii. Internal Causes

If two bodies of water are in free communication with one another and the density of one is increased by decrease of temperature or increase of salinity, then the heavier water will sink and flow under the lighter, and the lighter water will flow on the surface to replace the heavier, so that there will now be two currents in opposite directions. The currents in the Straits of Gibraltar are due to such a cause, as has been explained on p. 46. Currents of similar origin are formed in many parts of the world, and

the great subsurface current systems of the Atlantic and Indian Oceans, to which reference has already been made, are due to causes of this nature.

The direct observation of deep currents is a matter of considerable difficulty, but they may be often traced with relative ease by means of observations of temperature and salinity. Temperature and salinity also give us a great deal of information about such currents in another way. A density current is deflected by the earth's rotation in the same way as a wind current, and the force acting on a given unit volume of water will vary directly as its density and velocity and the sine of the latitude. Now it often happens that when the density at a number of places in a current is calculated from the temperature and salinity it is found that it varies from point to point and depth to depth in such a way that the water is in unstable equilibrium. In the Labrador Current, for instance, light water is banked up against the coast instead of spreading everywhere over the surface of the sea, and the obvious reason for this is that it is deflected to the right by the rotation of the earth. We can therefore calculate from the observations of density what the relative velocity at various depths must be to produce the arrangement found. We cannot calculate the absolute velocities, but only the differences between the velocities at various depths. If we know on other grounds the absolute velocity at any depth, then we can calculate it at all the rest.

iii. The Surface Currents

In each of the three oceans the north-east and south-east trade winds blow towards the equator and carry the surface waters with them as the Equatorial Currents, which flow westwards until they meet the land in their path. They split here into two branches which turn to

the right and left respectively, and set up great circular movements 'with the sun', to the right in the northern hemisphere and to the left in the southern. In the Indian Ocean only the southern circle is developed, because the northern part is limited by the Asiatic continent and because during the northern summer the direction of the wind is reversed when the north-east trade wind is replaced by the south-west monsoon. The equatorial currents are the mainspring of the whole circulation.

In the Atlantic Ocean the Southern Equatorial Current divides on Cape San Roque. The northern branch flows north-westwards along the coast to the West Indies, picking up in its course a tributary from the Northern Equatorial Current. The larger part of it flows between the islands of the Lesser Antilles and through the Caribbean Sea to the Straits of Yucatan and so into the Gulf of Mexico. The current is very strong everywhere in the Caribbean Sea, but the Gulf of Mexico acts rather as a reservoir and is almost free from current except where the flow from the Straits of Yucatan turns sharply to the right round the western end of Cuba and escapes through the Straits of Florida as the Gulf Stream with a speed which may reach 120 miles a day. In about 30° N. lat. it is joined by that part of the Equatorial Current which has passed outside the West Indian Islands. It continues its course in a northerly and easterly direction, skirting the coastal shallows of the United States and the Grand Banks of Newfoundland, and off the latter it turns almost due east. In mid-Atlantic it divides into two portions, and as its speed and breadth are now so different from what they were near the Straits of Florida it may be better called the North Atlantic Drift. The southern branch turns southwards in the latitude of the north of Spain, and then still more to the right until as the Canary

Current it joins the Northern Equatorial Current again. The northern part spreads fanwise and throws off branches to the English Channel and the western coasts of the British Isles, to the Faroe-Shetland Channel, and past the south of Iceland to the east coast of Greenland. The branch which passes through the Faroe-Shetland Channel and the Norwegian Sea finally sinks in the neighbourhood of Spitzbergen; it has no counterpart in the other circular systems in either geographical or economic importance.

The whole of the Gulf Stream System is relatively warm. In marked contrast is the East Greenland Current of cold water which overflows from the North Polar Sea and carries great masses of pack ice south-westwards to Cape Farewell, round which it turns to Baffin Bay. Here it meets other outflows from the Polar Sea and the combined waters flow south-eastwards as the Labrador Current, which carries great quantities of pack ice and bergs with it as far as the Atlantic traffic lanes in the first half of the year. Off the southern edge of the Newfoundland Banks it meets the Gulf Stream at right angles and is in part deflected by it and in part dives under it.

In the South Atlantic Ocean the southern branch of the Southern Equatorial Current, the Brazil Current, the Southern West Wind Drift, and the Benguela Current correspond to the Northern Equatorial Current, the Gulf Stream, the North Atlantic Drift and the Canary Current, but on the whole the circulation is less powerful than in the northern hemisphere. The Falkland Island Current is the counterpart of the Labrador Current and like it carries great numbers of bergs.

Eastwards of the thirtieth meridian the Atlantic Counter Current sets into the Gulf of Guinea between the Equatorial Currents. It is in part a compensation current replacing the water carried away by the latter and in part

due to the south-west monsoon which is fairly strongly developed in this region.

The currents of the Pacific Ocean on the whole resemble those of the Atlantic in that two great circular systems are developed. In the northern hemisphere the Kuro-Siwo corresponds to the Gulf Stream, and off the coasts of Japan is a rapid and powerful current, but its prolongation eastwards to the American coast and the southerly flow along the latter are far weaker than their Atlantic counterparts. The cold current which flows south-westward from Bering Sea and the Sea of Okhotsk corresponds to the Labrador Current, but it carries no bergs with it. In the southern Pacific Ocean there is a circular flow corresponding to that of the Atlantic; but there is no polar current corresponding to the Falkland Island Current. The Peru Current is the feeding ground of the guano birds, and when as sometimes happens it is displaced by a warm current from the north, El Niño, they die in their thousands from starvation and weakness, and even as far south as Callao the sulphuretted hydrogen given off by decaying fish darkens the white paintwork of ships in harbour there. Both the Equatorial and the Counter Currents are well developed.

In the southern half of the Indian Ocean the circular system is found again. The Southern Equatorial gives off branches which turn south-westwards on both sides of Madagascar. The one which flows to the westward of the island, the Mozambique Current, increases greatly in strength as it advances along the coast, and off the southern part of the African continent it is known as the Agulhas Current. Here it meets the West Wind Drift of the South Atlantic Ocean and after penetrating it to a certain extent is turned back eastwards together with the current which flows southwards outside Madagascar.

In the northern winter the north-east trade wind and the north-east monsoon strengthen one another and the general movement of the water in the northern Indian Ocean is westwards with a strong easterly counter current, but the land masses prevent any circular system as in the other oceans.

In the northern summer the south-west monsoon blows with considerable force and the general flow is to east and north-east. A very rapid current flows north-eastwards along the Somali coast into the Arabian Sea and escapes south-eastwards round Ceylon into the Bay of Bengal. As in the winter there is no circular current system.

In the region of the 'Brave West Winds', south of the American, African, and Australian continents there is a continual drift to the east which throws off branches into each of the oceans, and south of this, close to the shores of the Antarctic Continent, a slow set to the west.

METHODS OF INVESTIGATION

Temperature and Salinity

Temperature is observed at sea, but the determination of salinity with the necessary accuracy is not possible except in a large and well-equipped ship, and it will generally be necessary to preserve samples of the water for examination on shore. For this purpose the bottles known commercially as '6-oz. milk bottles with porcelain stopper, rubber washer and swing catch', holding about 170 c.cm., are very convenient and not expensive. A single determination of chlorine by the volumetric method requires at most 40 c.cm. inclusive of the water used for washing out the pipette, so that a bottle holds sufficient for two titrations, and a determination of density by weighing as well if this is to be done. Each batch should be

examined carefully when received from the makers and any bottle in which the washer appears to fit loosely should be rejected. Nothing but the best rubber should be used for the washers. All glass is slightly soluble in sea water on long standing; the brown variety used for beer bottles appears to be less affected than the other kinds. With good glass the solubility decreases with use and bottles previously used for holding sea water are to be preferred. New bottles may be improved by steaming followed by washing with hot distilled water. For all ordinary hydrographic purposes the solubility of the glass does not affect the determination of the chlorine by chemical methods, but the specific gravity becomes appreciably higher with time, and this would have some effect on the determination of density by weighing and on any method involving the refractive index. When the greatest accuracy is required bottles of special resistance glass should be used; they should be fitted with rubber stoppers.

Suitable boxes for packing the bottles can be had from the glass-makers. They should be divided into compartments so that each bottle is separated from the others, and lid and bottom should be lined with felt. No other packing is required. Hasps and staples should be fitted and rope handles; hand holes give admission to rats which eat labels. The number of bottles in a box may be from 30 to 42; a box of 42 bottles measures about 15 by 20 by 11 in. and weighs about 60 lb. empty.

Care should be taken to rinse out the bottle with some of the water and not to fill it within an inch of the stopper. Frost should be guarded against. Bottles with glass stoppers are not reliable, but sound, well-washed corks may be used in an emergency. The necessary particulars, date, time, position, depth, temperature, and ship, should be written in pencil on stout Manilla labels, which should

be tied to the bottle in such a way as to prevent the catch springing open.

There is one rule of the greatest importance, that is, that no thermometer should be used unless its errors are known. All patterns of thermometer used for marine investigation can be bought with a certificate of examination. In this country the certificates issued by the National Physical Laboratory at Teddington give the *correction* to be applied to the reading, but the Physikalisch-Technische Reichsanstalt at Charlottenburg shows the *errors* of the scale. Thus if the reading is 10° and the correction is $-0°{\cdot}1$, the true temperature is $9°{\cdot}9$; but if the error is $-0°{\cdot}1$, then the temperature is $10°{\cdot}1$. The glass of which a thermometer is made continues to contract for a longer or shorter time after manufacture and so causes a slight rise of the zero-point. For this reason the instrument should be tested at intervals, either by comparison with another of known accuracy, or better by means of melting ice. The thermometer is immersed in pure ice which has been crushed and washed with distilled water, so that the zero point is just visible. The vessel containing the ice should have an opening to allow the water to drain away, and sufficient time should be allowed for the temperature to become steady; the best way is to read at intervals, tapping the thermometer lightly each time, until no further change is seen. The experiment must be made in a room with a temperature above the freezing-point in order that the ice may melt. An error due to rise of the zero applies equally everywhere on the scale.

It is as a rule not possible to divide a small division by eye more closely than to one tenth; it follows that no correction need be considered which is less than one tenth of the smallest division shown.

Surface Observations

Surface observations are usually made by drawing a bucket of water over the side well clear of any discharge from the ship and reading its temperature with a thermometer, after which a sample of water is bottled off. Surface temperatures have little meaning in the second place of decimals, and a thermometer divided to half degrees is sufficient for the purpose if no subsurface observations are being made at the same time. If a vertical series is being made, it is better to make the surface observation with the same apparatus as is used in the depths if the condition of the sea allows; otherwise the surface temperature should be read to the nearest tenth of a degree C. Before reading, the thermometer must be well stirred about in the bucket and it must *not* be taken out of the water. The most useful kind of thermometer is that in which the graduations are drawn on a flat scale of milk-glass enclosed in an outer glass tube and are thus protected from the water; the bulb is not so enclosed and the instrument is very rapid. In this country this type is sometimes called an 'insulated thermometer'; care should be taken when giving an order not to confuse it with the thermometer used in the 'insulating water bottle' which is described below. They have no metal guard round them and can be easily cleansed from dried salt, so that it is permissible to use the same bucket of water for reading a temperature and preserving a sample. If a thermometer with a metal frame is used, such as the British Meteorological Office pattern, a fresh bucket of water must be drawn.

Observations below the Surface

A thermometer which has done much service in the past for measuring temperatures in the depths, but is no longer used, is the maximum–minimum thermometer, which depends for its recording upon the movements of two small indices which are pushed along the bore by the movement of the mercury. One registers the highest and the other the lowest temperature encountered by the thermometer while it is being lowered. It is plain that unless the temperature changes continuously in one direction as the depth increases the readings must be inaccurate. Modern investigations have shown that there is reason to believe that this is not generally the case in the open sea, so the maximum–minimum thermometer must be discarded. In any case it is liable to give false readings owing to movements of the indices caused by the vibration of the line during hauling in.

It is usual to combine the observation of temperature and collection of water samples in one operation, and so many instruments have been designed for the purpose that it is impossible to describe them all.

The Insulating Water-Bottle

The most convenient apparatus for measuring the temperature and collecting samples of water at depths not greater than about 1,000 m. is the insulating water-bottle, the Copenhagen model of which is shown in Fig. 7; the original Nansen-Pettersson model was closed by weights instead of by springs and was more lightly built. It is a device by means of which a specimen of the water may be brought up to the surface without undergoing any change of temperature. The body of the instrument consists of a series of concentric cylinders A, of which only

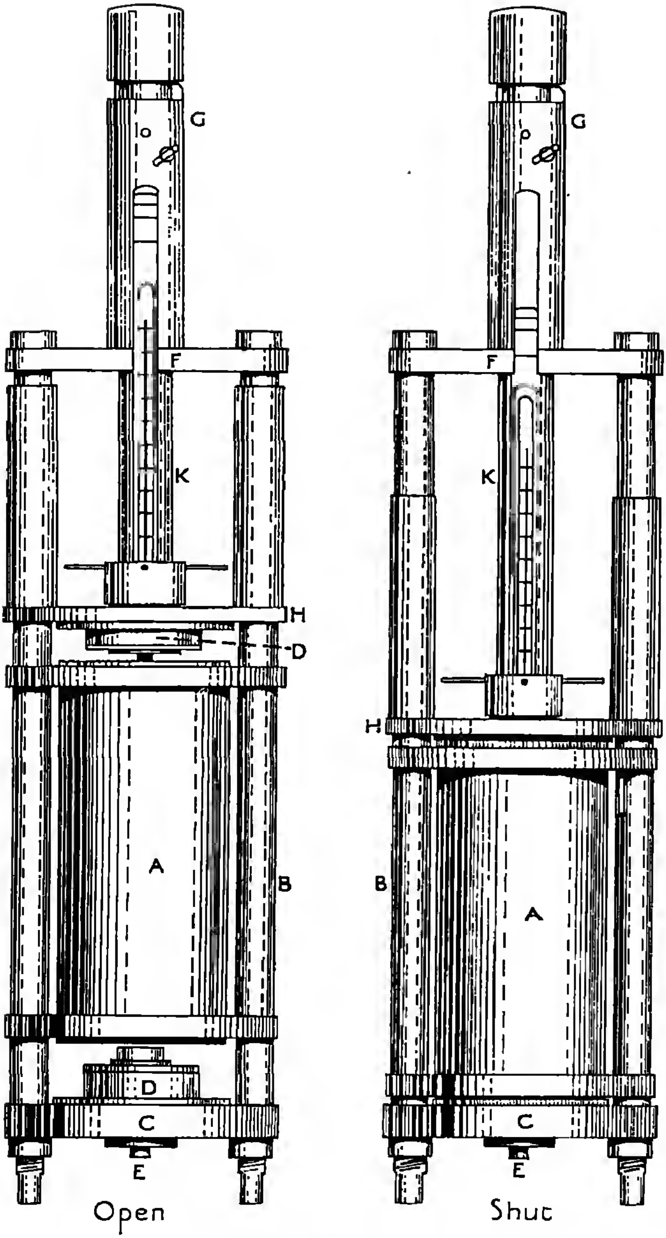


FIG. 7. The Nansen-Pettersson Bottle

the outer one can be seen in the drawing; it slides freely on the guides B, which are connected rigidly at the bottom by the circular plate C, which is fitted with rubber washers D and a tap E, and at the top by a cross-bar F, which carries the releasing mechanism G. Another circular plate H, with washers and a thermometer guard K, also slides on the guides. The thermometer, which is divided in tenths of a degree Centigrade, has a long narrow bulb and is sealed up in a strong glass sheath to protect it against pressure; it is kept permanently fixed in H with its bulb projecting some distance below it. The bottle is opened for lowering by raising the thermometer guard until the ball at the top is held by the releasing mechanism, and closed when at the required depth by allowing a messenger to slide down the line. The top plate H falls on to the body of the bottle, and the two together on to the bottom plate; the bottle is kept firmly closed by springs in the tubular guides. The temperature remains constant to 0°·01 C. for six minutes, even when the outside temperature is raised by 12° C., but begins to rise rapidly after seven minutes. When there is little or no change of temperature vertically the insulating period is longer, but there is another source of error which prevents the use of this apparatus in great depths. This is the cooling which it undergoes on decompression on hauling up. The correction can be calculated for the water contained, but not with any accuracy for the materials of which the bottle is made. The table on p. 61 contains the full amount of the correction due to the expansion of the water, but only half that due to the bottle itself. It has been found to be satisfactory by direct comparison with temperatures given by the reversing thermometer. The insulating water-bottle is quick in operation because the thermometer can come to equilibrium while it is being hauled up, but on the other hand

only one can be used on the wire at a time. It weighs 12 kg., holds 1,700 c.cm. of water, and is supplied by Professor Knudsen, of the Polytekniske Laereanstalt at Copenhagen.

EKMAN'S TABLE OF CORRECTIONS TO BE ADDED TO TEMPERATURES MEASURED BY THE INSULATING WATER-BOTTLE

Temperature of Water Sample	Depth in Metres											
	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200
−2	·00	·01	·01	·02	·02	·03	·03	·04	·05	·05	·06	·07
−1°	·01	·01	·02	·02	·03	·03	·04	·05	·05	·06	·07	·08
0°	·01	·01	·02	·02	·03	·04	·05	·05	·06	·07	·08	·09
1	·01	·01	·02	·03	·04	·04	·05	·06	·07	·08	·09	·10
2	·01	·02	·02	·03	·04	·05	·06	·07	·08	·09	·10	·11
3	·01	·02	·03	·03	·04	·05	·06	·07	·09	·10	·11	·12
4	·01	·02	·03	·04	·05	·06	·07	·08	·09	·10	·11	·13
5	·01	·02	·03	·04	·05	·06	·07	·09	·10	·11	·12	·14
6°	·01	·02	·03	·04	·06	·07	·08	·09	·11	·12	·13	·14
7°	·01	·02	·04	·05	·06	·07	·09	·10	·11	·12	·14	·15
8	·01	·03	·04	·05	·06	·08	·09	·10	·12	·13	·15	·16
9°	·01	·03	·04	·05	·07	·08	·10	·11	·12	·14	·15	·17
10°	·01	·03	·04	·06	·07	·09	·10	·12	·13	·15	·16	·18
11°	·01	·03	·04	·06	·07	·09	·10	·12	·14	·15	·17	·19
12°	·02	·03	·05	·06	·08	·09	·11	·13	·14	·16	·18	·19
13°	·02	·03	·05	·06	·08	·10	·11	·13	·15	·17	·18	·20
14°	·02	·03	·05	·07	·08	·10	·12	·14	·15	·17	·19	·21
15°	·02	·03	·05	·07	·09	·10	·12	·14	·16	·16	·20	·22
16°	·02	·04	·05	·07	·09	·11	·13	·15	·17	·19	[illegible]	·22
17°	·02	·04	·06	·07	·09	·11	·13	·15	·17	·19	·21	·23
18	·02	·04	·06	·08	·10	·12	·14	·16	·18	·20	·22	·24
19°	·02	·04	·06	·08	·10	·12	·14	·16	·18	·20	·22	·25
20°	·02	·04	·06	·08	·10	·12	·14	·17	·19	·21	·23	·25

Reversing Water-Bottles and Thermometers

The reversing thermometer, Fig. 8, records the temperature by separating the mercury which stands above a certain point on the stem at the required depth so that it can be read on a special scale after hauling up. The bulb is long and narrow; above it there is an irregularity in the bore of the capillary, which may be either a simple

contraction or 'knife-edge', or more commonly a short branch ending blindly, the 'appendix', as in the figure. Above this again there is an enlargement bent into an S-curve, or U-curve, or into a complete circle. The capillary has an unusually large cavity at the upper end and the amount of mercury is so great that it partly fills it when the thermometer is held with the bulb downwards. A small thermometer of the common pattern is sealed up together with the reversing thermometer in a strong glass sheath, and the space between the main bulb and the sheath contains mercury to hasten the interchange of temperature. The thermometer is lowered with the main bulb downwards, and after a wait of seven minutes for the attainment of equilibrium, it is reversed or turned upside down by a suitable mechanism. The mercury breaks at the appendix or knife-edge and runs to the other end of the capillary, where the temperature can be read off on the scale which is graduated for the reversed position. As a rule the thread broken off will have expanded after reversal, and a small correction must be made, which is calculated as follows. Let *a* be the apparent coefficient of expansion of mercury in

8

9

FIG. 8. Negretti and Zambra's Reversing Deep sea Thermometer

FIG. 9 The Appendix and loop bend of thermometer

the glass of which the thermometer is constructed, generally about $\frac{1}{6000}$, n the volume of mercury broken off expressed in degrees of the scale, and T and t the readings of the main and auxiliary thermometers respectively. The volume n is the reading of the main thermometer plus the volume which would have been broken off if the reversal had been made at 0° C.; this 'volume at 0°' is engraved on the stem. The correction is then $an(T-t)$; if it is large it should be recalculated, using the new value of T given by applying the first correction.

Reversing thermometers are the only means of measuring the temperature at great depths. They can be made so sensitive as to show differences of 0°·01 C., but they are liable to develop errors suddenly owing to a trace of residual air finding its way to the breaking-off point. When the error is large it is apparent at once and the reading can be repeated with another instrument, but if it is only a fraction of a degree there may be no reason to suspect it, and for this reason reversing thermometers should always be used in pairs. The makers provide instructions for dislodging the air and passing it back to the upper cavity. Other defects are locking of the mercury in the capillary after reversal, and a tendency for mercury which passes the breaking-off point after reversal owing to rise of temperature to join the rest of the thread instead of being held in the curved enlargement.

Reversing Frames and Water-Bottles

It is usual to collect a sample of water whenever the temperature is observed, so that there is little use for a frame without a water-bottle in combination with it. A reversing frame for two thermometers with messenger release is illustrated in Fig. 10; it can be fixed either at the end or on the side of the line. A similar frame with

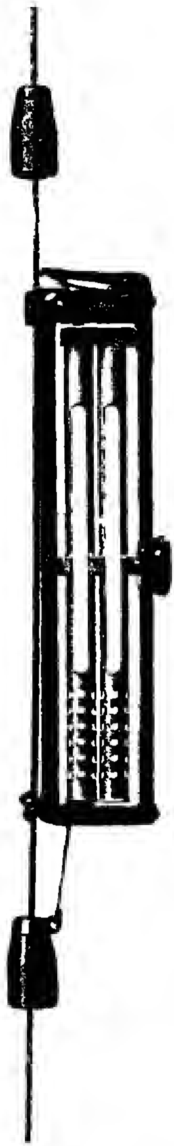


FIG. 10. Knudsen's Reversing Frame for Deep-sea Thermometers. One-fifth natural size

a propeller release is also made.

There are several types of reversing water-bottles to be had fitted to carry two thermometers and with either propeller or messenger release; they fit on the side of the line and as many as six can be used at once on a good steel rope of 3 mm. diameter, with great saving of time. The one shown in Fig. 11 is the latest Copenhagen model. The covers shut down parallel to the ends of the bottle, a great improvement on the earlier pattern in which they were carried on hinges, and are drawn together tightly by means of a strong spring passing through the centre of the bottle. The weight is $5\frac{1}{2}$ kg. and the capacity 1 litre. The pattern released by a messenger has a fitting by means of which each bottle as it is reversed drops a messenger on to another bottle fixed on the line below it.

Another pattern of reversing bottle which has been much used by its inventor is the Nansen bottle, which also

carries two thermometers. A much lighter model, that of Dr. Richard of Monaco, carries one only.

Method of Using Water-Bottles, &c.

All modern instruments are designed for use on steel wire, which is generally made up in the form of a very flexible cord with a diameter of 2 to 4 mm. and a breaking strain of 400 lb. or more. It is sometimes called sashcord. Single wire such as is used for sounding is liable to kink and is seldom used for water-bottles.

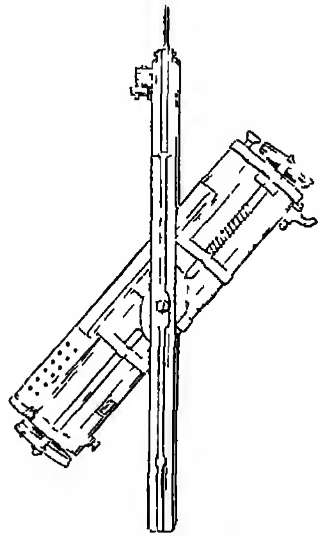


FIG. 11. Reversing Water-bottle

Water-bottles may be used from a davit or from a swinging boom; the latter requires one extra hand to work it, but it is far better as it makes it possible to swing the gear in for reading temperatures and taking samples of water, so that work can be carried out in decidedly rough weather. The wire paid out is measured by passing it over a block provided with a counting mechanism. This should be graduated in metres, as all the tables for making dynamical calculations of the speed of currents are on the metric system; a very convenient pattern is that showing single metres up to 1,000 m., with a circumference of 50 cm. The reading of the block should be corrected for the diameter of the wire by adding half the latter to the radius of the sheave. The radius of a sheave 50 cm. in circumference is 79·58 mm.; if the diameter of the wire is 2 mm., then the radius of the sheave

must be considered as increased to 80·58, and all readings corrected by adding one metre in each eighty shown. In most cases the drift of the ship will make the actual depth reached uncertain by at least this amount.

The wire is preferably stored on a drum with handles for heaving in and provision for a power drive if work in deep water is contemplated. A good brake is imperative.

The depths at which observations should be made cannot be laid down beforehand in unknown waters with any certainty. A good rule is to make observations at the surface and at 5, 10, 20, 30, 50, 75, 100, 150, 200, 500, 1,000 m., and then at each 500 metres and just clear of the bottom; the depth should have been first obtained by a sounding. The temperatures should be plotted on squared paper as they are obtained, and if this shows that there is a sudden change in the rate of decrease, additional observations should be made to find the depth at which this occurs. If the conditions are known beforehand to a certain extent, the list of depths may be modified considerably. The distance apart at which observing stations should be spaced will also vary with circumstances; in unknown waters the only guide is a careful study of previous work in similar areas and of the temperatures and soundings as they are obtained.

The spacing of surface observations made without stopping the ship will also depend upon the area. In the western part of the English Channel they might be made at intervals of ten miles, on the liner tracks between England and America at each hundred or two hundred miles, or at definite times in the day, which would be far more convenient.

The Salinity and Constitution of Sea-Water

Sea-water is pure water holding in solution a variable quantity, from about 40·5 parts per thousand downwards, of a mixture which we may call 'sea salt', and which is of practically the same composition everywhere as regards its main constituents. This mixture contains about 78 per cent. of sodium chloride (common salt), and smaller quantities of the chlorides, sulphates, bromides, and carbonates of magnesium, calcium, and potassium. In solution these substances are largely dissociated or ionized, that is, split up into two or more parts bearing electric charges. It is therefore not strictly correct to say that sea-water contains certain quantities of sodium chloride, magnesium sulphate and so on; we ought rather to say that we can make an artificial sea-water which is nearly the same as natural sea-water by dissolving certain substances in appropriate proportions in pure water containing sufficient carbonic acid gas (carbon dioxide) to keep the carbonates of calcium and magnesium in solution. The true composition of an average sea-water of a salinity of 35·00 per thousand is

Substance	Symbol	Parts per thousand
Sodium	Na	10·72
Magnesium	Mg	1·32
Calcium	Ca	0·42
Potassium	K	0·38
Chlorine	Cl	19·32
Sulphate ion	SO_4	2·70
Carbonic ion	CO_3	0·07
Bromine	Br	0·07
Total		35·00

An artificial sea-water may be made by dissolving in pure water containing carbon dioxide

		gram
Sodium chloride . . .	$NaCl$	27·2
Magnesium chloride . .	$MgCl_2$	3·8
Magnesium sulphate . .	$MgSO_4$	1·6
Calcium sulphate . . .	$CaSO_4$	1·3
Potassium sulphate .	K_2SO_4	0·9
Calcium carbonate .	$CaCO_3$	0·1
Magnesium bromide . .	$MgBr_2$	0·1

and making up to 1,000 grams. All the weights are calculated for the anhydrous substances.

Such an artificial water would serve to fill an aquarium in which to keep the hardier fish, but it is biologically unlike the true sea-water in that it lacks certain minute constituents, phosphates, silicates, nitrogen compounds, and so on, which are essential for the production of the minute plants which form the food of the smaller animals and indirectly of the whole of the animal population of the sea. True sea-water also contains in all probability traces of a substance resembling vitamins in its action. Traces of many other elements are also present; it is not known whether they have any influence on marine life, but on the analogy for instance of the necessity for traces of boron for the growth of beans the question is well worth investigation.

Having collected a sample of sea-water and observed the corresponding temperature, we have to determine in the first place the salinity, which may be defined as the total weight of salts contained in a thousand parts by weight of the water. The direct determination of the salinity by evaporating a known weight of water and weighing the residue is so difficult and tedious an operation that it is never used as a routine method. But since the composition of sea-salt is constant for all practical purposes, we may determine any one of the constituents and calculate the salinity from it by multiplying it by the

proper factor. The only constituent which is convenient for the purpose is the chlorine, or more strictly the sum of the chlorine and bromine, and fortunately this can be determined with ease and accuracy by Mohr's titration method in which sodium chromate is used as an indicator. The analysis should be carried out under the supervision of a skilled chemist, not because the operation is difficult, since any one with good colour vision should be able to learn it in a week, but because there are so many small possible sources of error in all chemical operations which cannot be guarded against in the instructions and yet would be obvious to any one with chemical training. The silver nitrate solution used is standardized against the 'normal water' supplied by the Laboratoire Hydrographique at Copenhagen in order to ensure that all results shall be comparable wherever the analyses are made, and the burette readings are converted to chlorine, salinity, and density at any temperature by means of Knudsen's Hydrographical Tables, 1901 (see p. 483). If the density *in situ*, that is, corrected for the pressure due to depth, is required, use must be made in addition of one of the tables drawn up by Bjerknes, Ekman, or Hesselberg and Sverdrup, to which reference is made in the bibliography at the end of this book (p. 483). The method of carrying out the titration is described in the article on 'Physical Oceanography' in Glazebrook's 'Dictionary of Applied Physics', vol. iii, p. 677.

We may also begin by determining the density at an accurately known temperature and then calculate the salinity from this by means of Knudsen's Tables. As a general rule this method is not to be recommended, as it is slower than titration and the possibilities of error are greater. In skilled hands, however, and in a properly equipped laboratory it gives excellent results.

At one time densities were determined by means of the common hydrometer in which a part of the stem projects above the surface. Unfortunately it has been found that its real accuracy is far less than its theoretical sensitivity, chiefly owing to the influence exerted upon the surface tension by a trace of grease, and it is now obsolete for oceanographical purposes.

Accurate determinations of density may be made by weighing a known volume of water at an accurately known temperature, or by weighing a suitable heavy body in pure water and in the sea water, also at accurately known temperatures, or finally by means of the total immersion hydrometer. The first two require a good balance and weights and facilities for keeping the temperature constant. The total immersion hydrometer requires a far simpler outfit and is accurate. It resembles an ordinary hydrometer with a very short stem and is adjusted to float in midwater, partly by dropping small ring-shaped weights over the stem and partly by small changes of temperature; the corresponding density is taken from the calibration tables which are supplied with the instrument. Its chief disadvantages are that it is slow and requires a rather large quantity of water. Several other pieces of apparatus have been designed upon the same principle.

Current Measurement

The measurement of surface currents by means of surface drifters thrown overboard to be picked up perhaps thousands of miles away requires considerable skill and an organization which is generally beyond the reach of those to whom this book is addressed. If, however, any yachtsman who is visiting little frequented parts of the world feels inclined to experiment in this direction he should

apply to the Challenger Society for advice, which will be given gladly.

Surface currents may be measured from a ship at anchor by means of a log-ship of the kind used before patent logs, but made much larger than usual. It is simply a flat piece of wood shaped as the sector of a circle and weighted along

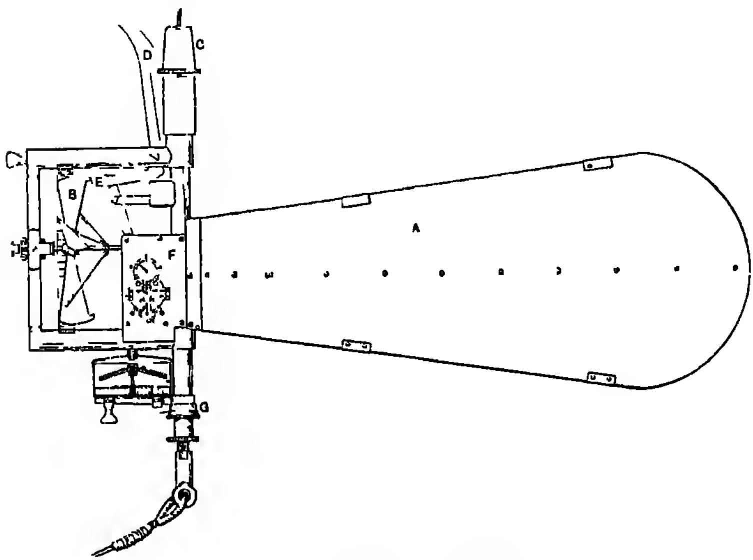


FIG. 12. Ekman Current Meter

A, vane; B, propeller, C, first messenger; D, arm to unlock and lock, E, end of D carrying slot which engages with B; F, box containing revolution-counter and shot-store; below this is the compass-box.

its curved edge with lead so that it floats upright in the water. It is allowed to drift astern at the end of a light line, which is marked at every 10 feet, and the length of line carried out in a given time is recorded.

For the measurement of currents below the surface the Ekman meter is probably the most convenient apparatus (Fig. 12). It consists of a hollow spindle turning freely by means of ball-bearings on a wire passing through its

centre, and bears on one side two vanes A, inclined at a small angle to each other, and on the other a framework carrying devices for recording the velocity and direction. The velocity is measured by the revolutions of the propeller B, which turns on centres supported in agate cups and is protected by a guard ring not shown; it is connected by gear wheels with the pointers moving on the dials on the cover of the box F. These pointers are sprung on to their pivots, and can be set to zero before each observation. The velocity of the current is calculated from the number of revolutions in a given time by a formula which must be determined experimentally for each instrument.

Beneath the box F is a compass, which can be quickly removed and replaced, and is kept in position by the thumb-screw shown below it. The needle is heavy, and the arms are inclined downwards, and one arm is deeply grooved on its upper surface. In the box F there is a store of small shot, which are released one by one by the rotation of the propeller, and fall through a funnel on to the centre of the needle, whence they run down the grooved arm on to the compass card. The latter is fixed and divided by raised partitions, and the shot falls into the compartment below the end of the arm, and so records the direction in which the apparatus was pointing at the moment. The card, really the bottom of the metal 'bowl,' is divided at every 10 degrees, in such a way as to record the direction from which the current comes, and not that in which it goes.

The meter is started and stopped by means of messengers. When it is being lowered to the required depth, the messenger C is not on the wire, and the arm D is more nearly vertical than shown in the drawing. The other end, E, is therefore slightly raised, and the projection on the propeller blade butts against it, so that the apparatus is locked. To release the propeller, the first messenger C

is allowed to slide down the wire; it forces D outwards into the position shown in the figure; the slot in E is now opposite to the projections, and the mechanism is freed. After a measured interval a second messenger is sent down; this is larger than the first, and hollowed out below so as to pass over it. It forces D still farther outwards, and again locks the propeller. The direction and velocity of the current then can be read off from the mean position of the shots in the compass card and the number of revolutions shown on the dial.

The wire should be as fine as possible to avoid stray, and if of steel any deviation which it may cause in the compass should be determined and allowed for. The sinker may weigh from 10 pounds upwards, according to the strength of the current. A torpedo-shaped sinker supported horizontally on a short vertical rod with fins to keep it head to current is far more efficient than other kinds. With currents of a mile an hour and over, in depths greater than thirty fathoms, the writer has found that it was not possible to feel and time the arrival of the messengers on account of the vibration of the wire. In such a case one must determine the time of fall of each messenger for various depths and plot the result on a curve. It will be seen that they soon reach a constant velocity, so that the time may be calculated from the depth. A simple telephone, consisting of a stretched string fastened to the centre of the bottom of a small box, is often useful.

The Ekman meter, of course, demands some fixed point, such as an anchored boat or ship, from which to work it, and in rough weather the velocities are not recorded accurately; under suitable conditions, however, it is very easy to use, and the results agree well among themselves. When tested at the surface from a boat, especially

if the current is slow, it is seen to wave from side to side continually, but this appears to be due to eddies; below the surface in currents of over a quarter of a mile per hour it points constantly in one direction.

The interval during which the propeller should be allowed to rotate depends on the strength of the current; when this is not known approximately, four or five minutes may be tried in the first instance.

The magnetism of an iron ship will deflect the compass of a current meter at considerable depths. Appreciable errors have been noted at 33 ft. below a vessel 76 ft. long and at 80 ft. below one 150 ft. long. The corrections can be calculated by the well-known theory of the compass in an iron ship.

Additional apparatus has also been made by means of which it is possible to work in rough weather from a ship that is not anchored, but the writer has not had any experience in its use. An anchor or heavy weight is made fast to the end of the wire; above this at the requisite distance the meter is fixed, and above this again, but below the surface, is a buoy, the floating power of which is not great enough to lift the anchor from the bottom, though it keeps the line taut. The buoy contains clockwork which drops the two messengers down the line to start and stop the mechanism. The wire above the buoy is slack, and the ship steams up to it.

Later models of the Ekman meter have been made, one of which is much heavier and stronger than that described, and another is designed to show the order in which the observations have been made.

There are many other current meters, some on entirely different principles, but they are useful to the professional oceanographer rather than to the yachtsman to whom this book is addressed.

Tidal Observations

As to the daily movements of ocean water, the subject of the theory of the tides is for the astronomer and mathematician rather than for the oceanographer. It will be enough to say that if a stay of any length be made in an out-of-the-way port or harbour accurate measurements of tidal movements would be found useful to the naval authorities and of real value.

A tide pole, well guyed, marked in feet and decimals, will do all that is necessary. A board carrying a light scale-rod, floating freely in a square tube of four planks knocked together, with holes in the bottom to admit the water, will be found easier to read as avoiding the wash of the waves. Both these require reading at frequent, say hourly, regular intervals, and if the observations are to be of real value they should be continued for a minimum of 15 successive days. An exact comparison between some of the observations and a permanent fixed mark on shore should be obtained and noted in the tidal record.

Note added 1st October 1928. A preliminary examination of some of the results obtained by the *Meteor* has shown that the system of the circulation of the Atlantic Ocean, sketched on pp. 43 and 44, is on the whole correct. The interchange of water is, however, far more active on the western side of the Central Ridge than on the eastern, since the eastern trough is largely blocked below 3,000 m. by cross ridges.

II (contd.)

The Alkalinity of Sea-water

BY W. R. G. ATKINS

If one takes a dilute solution of washing soda (sodium carbonate) or of caustic soda (sodium hydroxide) and to it adds a few drops of an alcoholic solution of phenol phthalein it is seen that the solution becomes a deep red. Taking a little of this solution in a test-tube and blowing down into it through a tube one finds that the red colour becomes less and less intense, passing finally through a faint pink to colourless. Now since sodium hydroxide and sodium carbonate are alkalis, and phenol phthalein is found to give a red colour with them, it is said to be an indicator of alkalinity, and the depth of the colour enables one to judge of the intensity of the alkalinity, which is not the same thing as the total amount of alkalinity, as will be explained later. Thus we see that alkalinity disappeared when air from the lungs was bubbled through, the solution being neutralized by the carbonic acid formed in the water when the carbon dioxide given off in respiration was passed into it. It is easily seen, therefore, that if we have a solution such as sea-water in which animals are living, and if we can get a measure of its alkalinity, we thereby have obtained information as to whether the animals in it are rapidly altering its conditions by their respiration. Now, sea-water taken from a rock pool, in which there are abundant algae during the summer months, is usually found to give a fairly deep colour with phenol phthalein. Sea-water from the open sea gives a much less intense colour if drawn from the surface or near it; if drawn from a depth of 100 metres it will probably give no colour at all with phenol phthalein. In the winter

it is found that even the surface water gives little or no colour with this indicator. These phenomena are explained by the fact that during the summer the abundant algae on the coasts and the diatoms of the plankton have sufficient light to enable them to carry on photosynthesis, abstracting from the sea-water more and more carbon dioxide, so that it becomes increasingly alkaline. A limit is set to this change by the growth and multiplication of the animals that feed upon the plants and are, of course, continually respiring, as are also the plants when not in good illumination. To be accurate, the plants too respire all the time, but when in good light, their respiration is masked by the amount of carbon dioxide they remove by photosynthesis. A study of the alkalinity of sea-water affords us, therefore, an idea of the relative amounts of plant and animal activity, indeed by an exact chemical estimation of the difference in alkalinity between the sea-water at any place in winter and in summer it is possible to arrive at a minimum value for the quantity of carbohydrate formed by photosynthesis. The value is only a minimum one, because, of course, the animals present in the sea have been respiring all the time and removing the algal plankton.

It is found, using phenol phthalein as an indicator and running in from a burette centi-normal sulphuric acid, that the sea-water of the English Channel off Plymouth requires 1 c.c. more acid to neutralize 100 c.c. of water in summer than it does in winter. Since this was the value obtained early in October, when the fall in temperature had resulted in a thorough mixing of the sea-water from top to bottom, it is possible to calculate the amount of carbohydrate formed in a column of water having a base of one square metre and extending from top to bottom.

Taking the depth found near the International Hydro-

graphic Station E 2, viz. 83 m. (half-way across the English Channel on the line Plymouth to Ushant), it is found that 1 kg. of carbohydrate, reckoned as dextrose, is formed per 4 sq. m. This amount may not seem very large, since it is distributed throughout a volume of water of 4 by 83 cubic metres, but it gives us the somewhat startling result that 250 metric tons of carbohydrate are formed under each square kilometre of the surface of the sea. There is, however, a simpler method of following the changes of alkalinity in the sea-water by means of noting the change in colour of an indicator added in carefully measured proportions to a measured volume of water and by comparing it with standards carefully prepared to be of a known alkalinity. For such comparisons phenol phthalein has been used, but it is not the most suitable indicator, because owing to its low solubility in water it soon separates out of the standards, so that they fade in colour. Furthermore, it gives no information about the condition of the sea-water once the latter has more than a very slight excess of carbon dioxide above what it would retain if shaken up thoroughly with the air, so as to be brought into equilibrium with the small amount of carbon dioxide contained in the air. Instead of phenol phthalein it is advisable to use another indicator known commonly as cresol red, which covers a range of alkalinity found in sea-water drawn from all but the greatest depths of the ocean, and in all save the most alkaline rock pools. It is, for example, quite suitable for the study of water in the tanks of the Plymouth Aquarium, which are always rather less alkaline than the water of the open sea, and are never sufficiently alkaline to give any colour at all with phenol phthalein. For these less alkaline regions it is instructive to confirm the results by using another indicator, phenol red, which is yellow in very faintly acid water, and a deep

red at the intensity of alkalinity at which phenol phthalein becomes colourless. We see, therefore, that it is not as suitable as cresol red for the more alkaline sea-water. For highly alkaline water such as that of the rock pools in summer, it is often advisable to use an indicator, thymol blue, which is a light yellow colour in the water of the open sea, but blue in water in which photosynthesis has brought about an increased alkalinity.

It may be added that by the use of suitable indicators it is possible to study the condition of all natural waters, from the most highly acid, such as in a bog pool, to the slightly acid, such as those of mountain rivers in districts where the rocks are granite or slate—very poor in lime—down to the alkaline waters (quite as alkaline as that of the sea) found in streams in limestone districts and extending to the very highly alkaline water which may be met with in ponds filled with calcareous water (viz. hard water) in which an abundance of plant life is actively developing; in these it is by no means uncommon to find the water giving an intense blue with thymol blue.

It would be a great mistake to consider sea-water alone without having any ready means of comparing it with fresh waters, and such a comparison is conveniently effected by referring waters acid, neutral, or alkaline to one scale, viz. that of the concentration of hydrogen ions found in them. An outline of how this scale is arrived at and of how the measurements may be made is given in the following pages, but as this book is intended to deal with marine life only the applications of the method will be limited to those necessary for the study of sea-water.

Hydrogen Ion Concentration

In acidimetry the alkali is added to the acid till an indicator reaches a certain tint which is said to indicate neutrality. Gravimetric work proves that this is the stage at which a salt is formed, such as sodium chloride from hydrochloric acid and sodium hydroxide, no trace of either acid or alkali remaining over. Along with the salt, water, in addition to that already present, is produced. Neutrality then is the point at which only water and the salt are left. The salt gives sodium ions and ions of the chloride radicle, both in quantity, since its solution is a good conductor of electricity. The water gives very few ions, as is shown by the fact that it is a poor conductor. It does, however, give off a minute number, and from its conductivity Kohlrausch and Heydweiller calculated what their concentration must be. It is necessary at this stage to consider pure water and neutrality.

Pure Water and Neutrality. Pure water dissociates into hydrogen and hydroxyl ions, and the product of the ionic concentrations is constant at a constant temperature, namely, $[H^+] \times [OH^-] = k[H_2O]$. Because the dissociation proceeds only to such a small extent, the constant k may be replaced by another constant, thus $[H^+] \times [OH^-] = K_w$. Since the ions are produced by pure water in equal numbers, the concentration, reckoned as usual in gram-equivalents, is the same for both. A solution is accordingly termed neutral when the hydrogen and hydroxyl ions are present in equivalent amounts, as in pure water. With an acid solution the hydrogen ion is in excess, and the hydroxyl is correspondingly reduced, since the product is constant. In alkaline solutions hydroxyl ions preponderate; but as the product is constant, it is possible and convenient to state the reaction of the solution in terms of hydrogen

ion concentration rather than in terms of the hydroxyl. One scale is therefore obtained, the hydrogen ion concentration scale, instead of two diverging in opposite directions from the concentrations of the two ions in pure water, namely, from neutrality.

It may be stated that the value given by Michaelis is $K_w = 1 \times 10^{-14}$ at 22° C. Since the two ions are present in equal concentrations, each is present to the extent of 1×10^{-7} gram-equivalents per litre, for $(1 \times 10^{-7}) \times (1 \times 10^{-7}) = 1 \times 10^{-14}$. Since the equivalent weight of hydrogen is 1 and hydroxyl 17, the actual weights are for hydrion 1×10^{-7} and for hydroxylion 17×10^{-7} grams per litre. Each litre of pure water therefore contains one ten-thousandth of a milligram of hydrogen ion, and seventeen ten-thousandths of a milligram of hydroxyl ion. The pure water mentioned is, of course, the purest obtainable, free from traces of carbon dioxide, of ammonia and of salts derived from the solution of the glass vessel containing it.

Acidity and Alkalinity. Having now defined neutrality as the condition in which the hydrogen and hydroxyl ions are present in equal numbers, we may define acidity as that state in which there are present a greater number of hydrogen ions than of hydroxyl, alkalinity as that in which the hydroxyl ions are the more numerous. In future we shall, as a rule, consider only the hydrogen ion concentration, for the product of the two ions is constant. Thus if the hydrogen ions are increased tenfold, the hydroxyl are reduced tenfold, water being produced.

At this stage it is necessary to consider the difference between hydrogen ion concentration and the total replaceable hydrogen as measured by titration. The former is a measure of the hydrogen ion effective at any instant, and it is this quantity, rather than the titratable acidity, that is

concerned in regulating the precipitation of hydroxides—and therefore their solubility—the action of enzymes and many biological processes. For example, equal volumes of N/100 hydrochloric and acetic acids require identical amounts of alkali for their neutralization, but the former solution has a far greater concentration of hydrogen ions than has the latter, since in dilute solutions hydrochloric acid is almost completely ionized, whereas acetic is not; it is accordingly said to be a weaker acid. If it be assumed that the ionization of hydrochloric acid is complete at this dilution, its concentration in terms of hydrogen ions is C_H or $[H^+] = 1 \times 10^{-2}$ grams per litre, namely, 10 mg. per litre. This may be written $[H^+] = \frac{1}{10^2}$, or $p\mathrm{H} = \log\frac{1}{[H^+]} = 2$. This symbol, pH, is thus defined as the logarithm of the reciprocal of the hydrogen ion concentration, expressed in grams per litre, or as the negative power to which ten has to be raised to show the concentration in grams per litre. It may at first sight appear to be both cumbersome and unnatural to use such an expression as pH, viz. $-\log[H^+]$, to denote hydrogen ion concentration, but in practice it is extremely convenient, and gives simple numerical values which are easily remembered. Moreover, since an increase of unity in a pH value denotes a decrease to one-tenth in the hydrogen ion concentration, it is obvious that for any graphical presentation of results difficulties arise when the changes are of the order of 10^{-3} or 10^{-6}, yet these are quite commonly found. For certain purposes it is at times convenient to use $[H^+]$ or C_H or even C_{OH} values; as a rule, however, for sea-water, the use of C_{OH} values is to be considered undesirable as it necessitates the conversion of the data into pH values if any comparison is to be made with similar researches in fresh

waters of low calcium content. In general the units used should be equally applicable to limnology and to marine investigations.

An additional reason for using the *p*H notation is that in the fundamental electrometric determination of hydrogen ion concentration the relation deduced is equated to $\log \frac{1}{[H^+]}$. It may be explained that by the measurement of the electromotive force of a cell which has different concentrations of hydrogen ions at each electrode it is possible to determine the hydrogen ion concentration of certain mixtures of acids, salts, and alkalis, so that these may be used as standards. By the use of a series of these 'buffer' mixtures with appropriate indicators, it is possible to have a very convenient and instructive method for measuring hydrogen ion concentration.

Buffer Action. If acid is added to alkali, after a certain amount has been run in, a neutral solution is obtained. With a strong acid, such as hydrochloric, the addition of the alkali in successive portions results in a progressive diminution in hydrogen ion concentration, as may be seen from the fact that the acid was largely ionized at the start. But with a weak acid the neutralization of the hydrogen ions existing at any instant results in a new equilibrium being attained by the remaining undissociated molecules of the acid, which become ionized to about the same percentage as before. The alteration in the hydrogen ion concentration is therefore much less over a considerable range. If the results are plotted with *p*H values as ordinates and cubic centimetres of alkali added as abscissae, the slope of the curve will be less steep for the weak acid than for the strong, except quite close to the neutral point. Curves illustrating this are given by W. M. Clark in his book, 'The Determination of Hydrogen Ions', which is

the authoritative work on this subject. It contains directions for making up standard buffer solutions, and has a useful coloured chart showing the tint assumed by various indicators at different hydrogen ion concentrations. This can be purchased separately, and suffices for approximate work, for which its use may replace that of standard buffer tubes. A weak acid thus has a considerable 'buffer action' in preventing rapid alterations in *p*H value; the same is true of weak bases.

Colorimetric Determination of Hydrogen Ion Concentrations. As previously mentioned, various mixtures of weak acids or alkalis or of the corresponding salts are standardized by means of the electrical method. The mixtures usually made up cover a range of $C_H 1 \times 10^{-1}$ to $C_H 1 \times 10^{-10}$ or 10^{-11}, viz. *p*H 1 to *p*H 10 or 11. For this purpose various mixtures have been devised, the most widely used being those of Soerensen and of Clark and Lubs. The latter are made up at intervals of 0·2 in terms of *p*H. Methods have also been devised for colorimetric determinations without recourse to standard buffer solutions, by employing, in varying number, drops of indicators in pairs of test-tubes. In one set the full acid tint is developed; in the other the full alkaline tint. On looking through the pairs of tubes intermediate tints are seen.

The salts used for preparing buffer mixtures include phthalates, phosphates, and borates. Citric acid, boric acid, glycocoll, carbonates, and acetates have also been used. These are mixed in varying proportions either among themselves, with hydrochloric acid, or with sodium hydroxide.

The most serviceable indicators are in the main members of the sulphone phthalein series. Of these dibromo thymol sulphone phthalein changes from yellow at *p*H 6 to deep blue at *p*H 7·6, being a clear green at *p*H 7. It is

known as brom-thymol blue for short, and is much used, as it covers the neutral point. On the alkaline side phenol red, cresol red, and thymol blue are reliable indicators; on the acid brom-cresol purple, brom-cresol green, brom-phenol blue and thymol blue (acid range) may be used. Methyl red covers the same range as brom-cresol green, but the latter is more permanent, and on this score has advantages. These indicators are made up in 0·02 or 0·04 per cent. solution; the addition of one drop per cubic centimetre of test solution is about right as a rule. With unbuffered solutions, such as 'soft' natural waters, the indicator should be reduced to a minimum so as not to alter the reaction of the water. It is well to keep the indicator at about the middle of its range, so as to minimize errors from this source. Thus brom-thymol blue made up ready for use should be neither yellow, in which case it may be too acid, nor blue, when it may have excess of alkali, but green—the colour which proves it has no excess of either.

Colorimetric Determination of Hydrogen Ion Concentration of Sea-Water

For this purpose the buffer mixtures of Clark and Lubs may be used, but a correction must be made owing to the effect of the salt upon the colour of the indicator. For the indicators recommended, viz. those of the sulphone phthalein series, the effect is to give a result showing the water to be more alkaline than in reality it is. For the water off Plymouth in the open sea, 0·18 is to be subtracted from the *p*H value as found by comparison with Clark and Lubs buffer mixtures; for example, water which appeared to be *p*H 8·42 was in reality 8·14 using cresol red as indicator. This correction is made because the standard electrometric method is not thus affected by

the salt. It is, however, convenient to have a set of buffer tubes specially made up for use with sea-water; such a set has been prepared by McClendon as follows. Using distilled water, boiled to remove carbon dioxide, a solution is made containing 18·6 gm. of boric acid and 22·5 gm. of sodium chloride to the litre. The boric acid used is recrystallized and dried in a desiccator, not by heat. The other solution contains 28·67 gm. of borax and 19 gm. of sodium chloride to the litre and has the same salt action on the indicators that the first solution has. The borax should be recrystallized and dried in dry air short of efflorescence, or it may be dried in a desiccator over a saturated solution of sodium bromide. If kept at a low temperature, borax may crystallize out of the stock solution, and this must be made uniform before mixtures are made. The same applies to the mixtures. The proportions in which the two solutions should be mixed to give a series of standards suitable for use with sea-water are shown in the table.

It is convenient to work with 10 c.c. of sea-water which should be as freshly drawn as possible, to this should be added 0·50 c.c. of the indicator, such as cresol red. The latter should be 0·02 per cent. and the solution should not be a clear yellow or a deep red, but intermediate in colour between the two. The measurement of the amount of indicator should be carried out with care, using a pipette divided into hundredths of a cubic centimetre. The addition of drops of indicator which suffices for approximate determinations accurate to 0·1 on the *p*H scale, does not suffice for determinations carried out upon sea-water in which accuracy of 0·01 should be aimed at. This is desirable because the annual variations are small in the open sea, and because the data already available have conformed to this standard.

It should be mentioned that in making a comparison the sea-water tubes should be allowed to attain to the same temperature as those of the standard buffer tubes before a comparison is made. It facilitates comparison to examine the tubes side by side standing on a piece of white paper, across which parallel lines have been ruled, and to slant the tubes so that a greater thickness of liquid intervenes between the eye and the lines ruled on the background. The glass used for the tubes should be hard glass such as is prepared by makers in England and Scotland. It is now quite unnecessary to import foreign glass for this purpose, although this is sometimes advocated—a superstition devoid of foundation. A simple way to test whether the glass is, or is not, sufficiently resistant is to wash it with distilled water, fill it with the same and place it in a bath of boiling water for one, or even two hours. On cooling and adding the indicator no pink colour should appear, whereas with soft glass the distilled water will have become markedly alkaline as shown by the intensity of the pink tint assumed by the cresol or phenol red.

The tubes containing the standard buffers may be protected against the air by closing them with small rubber caps, and have been known to keep for several months when thus protected. If desired, however, they may be drawn out and sealed up. To prevent the growth of moulds it is advisable to add a few drops of toluene to the boric and borax stock solutions from which the buffer tubes are prepared.

The table (p. 89) gives in the first column the percentage of the boric mixture. In the second that of the borax. In the third column is shown the pH of sea-water, which is 0·4 normal with respect to chloride. This value for pH is correct whatever indicator is used. In the fourth and fifth columns similar pH values are given for sea-water, 0·5

normal and 0·6 normal, corrections having been applied for the salt error of the sulphone phthalein indicators.

In finding the normality of sea-water, allowance must be made for the fact that by the addition of 0·50 c.c. of indicator to 10 c.c. of water the original concentration has been altered somewhat.

The water off Plymouth is not far from 0·5 normal, so that the buffer tube in the 0·5 column and shown as 8·15 is labelled 8·14 for use with the water here.

The tubes may be marked with a yellow grease pencil or more permanently with ink made by adding a spirit solution of crystal violet, or some such spirit soluble dye, to Friars' balsam, as ordinarily sold at a pharmacy. If too much spirit is not added a mixture is obtained which flows evenly from an ordinary pen. Should too much spirit be added, if the stopper is allowed to remain out of the bottle a suitable consistency may be obtained.

One further rather obvious precaution may be mentioned, viz. that the diameter of the tubes used should be closely the same, 12 mm. is a suitable size.

For ordinary use with water from the open sea, 0·5 normal as regards chloride, it suffices to make up the standards only between *p*H 8·00 and 8·30, viz. a set of eight. The table, however, ranges from *p*H 7·45 to 9·05, and for the extreme values it is necessary to use thymol blue at the alkaline end, and though cresol red may be used at the acid end, phenol red is preferable.

As examples of the *p*H values met with the following may be quoted: the Faroe Islands results were obtained in May and June and the Mediterranean results between June and September. (See opposite page.)

These results obtained by Palitzsch show clearly that the alkalinity decreases with depth. This is due to the fact that photosynthesis is carried on only in the upper

			*p*H of sea water	
'Boric'	'Borax'		0·5 N.;	0·6 N.;
		0·4 N ; all	sulphone	sulphone
per cent.	per cent.	indicators	phthaleins	phthaleins
79·5	20·5	7·50	7·45	7·40
78·0	22·0	7·55	7·50	7·45
76·0	24·0	7·60	7·55	7·50
74·0	26·0	7·65	7·60	7·55
72·0	28·0	7·70	7·65	7·60
70·0	30·0	7·75	7·70	7·65
68·0	32·0	7·80	7·75	7·70
66·0	34·0	7·85	7·80	7·75
64·0	36·0	7·90	7·85	7·80
62·0	38·0	7·95	7·90	7·85
60·0	40·0	8·00	7·95	7·90
58·0	42·0	8·05	8·00	7·95
56·0	44·0	8·10	8·05	8·00
54·0	46·0	8·15	8·10	8·05
52·0	48·0	8·20	8·15	8·10
51·0	49·0	8·22	8·17	8·12
49·5	50·5	8·25	8·20	8·15
47·0	53·0	8·30	8·25	8·20
44·5	55·5	8·35	8·30	8·25
42·0	58·0	8·40	8·35	8·30
39·5	60·5	8·45	8·40	8·35
37·0	63·0	8·50	8·45	8·40
34·5	65·5	8·55	8·50	8·45
32·0	68·0	8·60	8·55	8·50
29·0	71·0	8·65	8·60	8·55
26·0	74·0	8·70	8·65	8·60
23·0	77·0	8·75	8·70	8·65
20·0	80·0	8·80	8·75	8·70
17·0	83·0	8·85	8·80	8·75
14·0	86·0	8·90	8·85	8·80
11·0	89·0	8·95	8·90	8·85
8·0	92·0	9·00	8·95	8·90
4·5	95·5	9·05	9·00	8·95
1·0	99·0	9·10	9·05	9·00

Depth in Metres	North Sea East of Faroe Islands *p*H	Atlantic West of Portugal *p*H	Mediterranean between Sardinia and Italy *p*H	Black Sea *p*H
0	8·13	8·22	8·23	8·34
100	8·09	8·13	8·21	7·86
400	8·03	8·04	8·19	7·53†
1000	7·98*	8·01	8·14	7·26
2000		7·95	8·09	
3200			8·07	

* 700 metres.　　† H_2S below 180 metres.

and well-illuminated portions of the sea, though as the season progresses there is a considerable amount of vertical mixing.

To illustrate the seasonal change in alkalinity and the increase in this variation as the shore is approached the following table for *p*H, temperature, and salinity may be quoted for the Plymouth district.

	*p*H	Temp. °C.	Salinity %
Aquarium tanks, normal	7·60–7·45	18·9–9·1	36·14–36·85
do. abnormal	8·00–7·05	—	—
Rock pool . . .	8·57–8·01	21·4–8·2	—
Shallow water . .	8·42–8·01	19·2–8·2	—
L1. Plymouth Sound .	8·29–8·01	16·3–8·2	35·00–30·69
L2. do. Breakwater	8·27–8·07	16·1–8·8	35·17–32·25
E1. About 20 miles out to sea from the Breakwater	8·27–8·14	16·2–9·9	35·40–35·13

Minor Constituents of Sea-Water

In addition to the salts which make up the greater part of those dissolved in the water of the sea there are a large number of others. Of these certain ones, such as those of gold, are of no ascertained importance. Others, such as the salts of phosphoric, nitric, silicic, and arsenious acid are of very great importance, especially the phosphate and nitrate. These are taken up by plants, microscopic or fixed algae, for all of which phosphate and nitrate are essential; by some, the diatoms, silicate is used to form their outer covering and many take up arsenic, though it has not been proved that they cannot grow without it. Iron salts, too, are a necessity for plants, though only present in sea-water in minute amounts. Delicate colorimetric methods have been devised for estimating the traces of these indispensable salts, of which phosphate is present in winter around England to the extent of only about forty parts and nitrate nitrogen about two hundred parts per thousand million, or, what is the same, milli-

grams per cubic metre of water. In summer no phosphate or nitrate remains in the surface water, and these substances may be much reduced in amount down to 70 m. or more. Since they are essential for plant growth, and since the entire animal population of the sea depends (just as on the land) ultimately upon plants for its food, we see that the abundance of life in the sea is regulated by the minute amounts of these salts—provided there is sufficient light for the plants to use them up completely, which there is not in winter; neither is there enough light in the deeper waters of the ocean, which consequently act as storage houses for phosphate, nitrate, &c. Where rocks or banks occur in deep water the bottom water may be caused to well up, bringing its abundance of essential salts. Accordingly microscopic plants flourish, the zooplankton becomes enriched, and fish abound.

Light, Transparency, and Colour

The measurement of the actual illumination at any depth below the surface may be carried out in a variety of ways, such as by chemical methods, by the exposure of photographic plates at given depths, and by photoelectric cells. Mention of some of the results obtained by the latter method and their bearing on the distribution of plants is made on p. 168. It must be remembered, however, that the composition of the light varies with depth, and that different methods may be most sensitive for different regions of the spectrum, so that only a partial picture of the true light conditions is furnished by any one method.

Interesting observations of the transparency of seawater in different localities may be made by the simple method of lowering a white disk to the depth at which it disappears from sight. A circular disk, 20 to 30 cm. in

diameter, coated with a *flat* white paint, should be used. This should be lowered on the shady side of the ship to the depth at which it disappears; the depth at which it reappears on being hauled up should also be noted. Care must be taken to keep the line quite vertical, and a water telescope should be employed if feasible.

The colour of the water should also be noted.

III

TROPICAL SHORES; CORAL REEFS AND ISLANDS

BY J. STANLEY GARDINER

A.

TROPICAL SHORE COLLECTING

The naturalist on his first visit to a tropical land is often as much disappointed with what he sees on the ocean shores, as he would be if he had transferred his activities from the relatively rich waters of Cornwall to the barren beaches of Picardy. He usually arrives at some continental port, and he probably wanders to the sandy beach nearest to the open ocean. The tidal rise and fall is relatively small, and he is confronted with lines of breaking rollers, each swirling foam-flecked water several yards up the beach. Spring tides seldom rise and fall more than 24 in. beyond neaps, so that in the highest springs there are often no great flats exposed; even in dead calm weather the perpetually breaking waves. He, who wades out a few yards, feels the undertow, and he who is venturesome is swept off his feet to swim in on the surface waters, a 'game' only to be played on a rising tide. In any case he need not think he can collect in spite of difficulties, for there is almost nothing living to collect as the bottom is of sand in such a state of motion that it is suitable to few forms of life.

The most the naturalist can do is to try and get some idea from the material which forms the beach, of what life exists in the waters outside. He will find there an epitome both of the complete bottom life to 10 fathoms at least and of the larger pelagic organisms (plankton) as well. The basal material of the beach depends on the

neighbouring lands, but frequently more than half of its substance is derived from organisms still living in the sea. The colour is often extraordinarily white, due to organic remains, and spectacles of Crooke's glass with toric lenses are called for. Omitting what is microscopic, the shells of the pelagic Foraminifera, which form globigerina ooze, may be picked out, all polished and spineless. Only about 30 species share in the formation of the 50 million square miles of this ooze, and generally the shells of about half of these can be found; several species of Globigerina with their joined series of chambers; Hastigerina, similar but set with thick rods of lime; Orbulina, the coiled shell enclosed in an outer sphere up to 2 mm. across; Pulvinulina, a flat spiral of firmly joined chambers; Sphaeroidina, two visible chambers only; and Candeina a lumpy little mass of chambers differing in appearance in every view. Much broken fragmentary material will prove on examination to belong to the shells of various pelagic molluscs, Pteropoda and Heteropoda, also ooze formers, but often peculiarly abundant near coasts. These are recognizable at once as being thin and fragile, almost transparent, but perfect forms of a few mm. long of the coiled Limacina, of the Creseis tube, of the Clio 'vase', and of the Cavolinia 'seed husk', each of the last three pointed at the base, may be sought. If the day is lucky, there will also be secured odd shells of the heteropods, Atlanta and Oxygurus, and high up the beach, probably blown over the crest, will assuredly be found an odd shell or two of Ianthina, a thin coiled form of ultramarine colour 3 cm. across, accustomed usually to float on the surface of the ocean by means of a bubbly mucous mass secreted by the foot gland. The search for the latter generally reveals the coiled shell of Spirula about 1½ cm., its coils not touching each other and its surface quite polished and showing no trace of its

chambers. Then there are 'pens' of various other cephalopods, calcareous to horny, and a very occasional shell of the female Argonauta, a float organ not homologous with any other shell.

The above shells all belong to the ocean fauna, but are the first organic remains to be noticed, as, being of light texture, they lie upon the surface and are swept up the beaches. With them, especially on the upper ridge, if the land allows such to exist, will be found light plant remains, leaves of Cymodocea, Halophila, and Zostera, marine phanerogams, which materially help to bind together sand and mud below tide level; the first, by the accumulation of its grass-like dark leaves, often forms the ridge on protected beaches. Conversely, there are few or no remains of Laminaria, Fucus, or any of the similar algae that are characteristic of temperate zones, but the Sargasso weed (Sargassum) may be found on any tropical beach. In place of these seaweeds we can collect small blue-green and green algae, made up of hair-like growths of filaments and of stems perhaps branching, of flat 'leaves' to low spreading plates, and of more or less tubular structures. All are small, some being naturally so, while others are stunted by the rush of the waves over them. There are numerous species of Caulerpae of many aspects, and then there are the Siphoneae, which are encrusted with carbonate of lime, this skeletal matter persisting as a hollow shell. They are of any shape, but all small, and all easily break up; the species of Halimeda, bunches of flattened stems with disk-like 'leaflets' attached end to end, are the most abundant. Of other plant remains, those of the Lithothamnioneae, brown-red algae which deposit carbonates of lime and magnesium in their substance so that they form stone, will be found in the lower levels of the beach, unless cast up by a gale, and then generally bedded below lighter material.

They show no structure, their lime being laid down densely, and they are peculiarly white and opaque and vary from tiny rounded branchlets and marbles to large balls. They are not peculiar to the tropics, being indeed more abundant in temperate seas, where banks are often covered loosely with their little rounded but densely branched growths, and where the flat rocks at low spring tides are made brilliant by the red, orange, pink, and violet incrustations of the Squamariaceae. They are, however, more conspicuous here on account of the absence of seaweeds, and for the reason that they grow to great size and thickness and resist the heaviest breakers.

Animal remains from the bottom fauna cast upon our beach reveal the existence of all the same groups of animals as live in similar seaward positions in temperate zones, except that there is much greater variety in species, seldom that dominance of a very few kinds of bivalve and spiral molluscs, and of sea urchins and starfishes, often so characteristic of the temperate zones. Filamentous and incrusting Polyzoa are never so common, and starfishes are always everywhere relatively scarce in species; bivalves are as numerous as in temperate zones, but spirally coiled gastropods are enormously abundant, especially the tiny forms, of which often the veriest novice may easily find over 50 species in a bucket of the sand. The larger shells are brilliantly coloured cowries, elongated gastropods equally gaudy, spider shells, and so on, either buried or cast up by gales above the tide; limpets and similar shells are rare. Then there will be found dried up leathery masses of various alcyonaceans and sponges, often gritty owing to their contained spicules, and fragments of all sorts of coral skeletons. The latter are mostly white, but some have dark red basal markings, and some violet tips. They comprise true colonial corals with plates (septa) in

the cups which house their anemones (Madreporaria), flat plates (Millepora) and various branching species quite similar (Hydrocorallinae), with tiny round holes and much denser skeletons, blue plates (Heliopora), masses of tiny parallel red tubes fused together (Tubipora), and branching and often anastomosing brown, red, yellow, or black branches, almost like dried plant remains (Gorgonaceae and Antipathariae). Unless the beach be a peculiar meeting-place of winds, tides, and currents, all of these can never be present in the same place in the old world, for the existence of true corals and Millepora implies coral flats extending some distance seawards, and of gorgonians steeper ocean slopes. Crustacean remains are all too much broken up to be of use, but there are few beaches on which crabs do not scamper, and the semi-land forms (Ocypode) of the upper dry part are interesting diggers, running down occasionally to the water to wet their gills. Worm remains are rare, dry or moist, as compared with our coasts, but in any case fresh animal remains are at once seized by these burrowing crabs or by Anomura (Hippa, Remipes, and Albunia) which live in the sand, following the edge of the tide as it ebbs and flows.

This study of the beach is no waste of time on the part of the naturalist, for from his deductions he can, aided by charts, lay out his plan of campaign in accordance with his desires. He will have a fair idea of the bottom off his beach to 10 fathoms or more, and he will be able to judge whether the beasts he wants can or cannot occur there. He will, however, not be satisfied with his sandy beach alone, and doubtless he will wander to rocky points and into deep bays. Beaches of loose stones, pebbles, and rocks are the most hopeless of collecting grounds, and the pools below the same, unless protected from the waves, appear superficially to be almost barren of life. In bays

he may find upgrowing banks formed mainly of carbonate of lime skeletons, either of corals or of Lithothamnioneae. Both of these leave in their skeletons a quantity of organic matter, capable of digestion, and in consequence the rock they make is riddled by all sorts of boring organisms. The actual surface of rock is seldom entirely flat or rounded, and all sorts of nooks and crannies are left in which animals shelter. Where there is much branching of corals, the amount and variety of shelter is enormously enhanced, and a new fauna of fish and crustaceans is revealed, darting and crawling in and out of the stems.

There is always much decay on organically formed shoals, and all sorts of crevices are found under the growing masses of the building organisms, many of which will ultimately topple over; similar cavities are also formed by coral masses growing together. In all such places sand and bits of coral accumulate, while organic detritus gets swept in. The result is seen in a new set of animals that oecologically is divisible into four faunas. The first of these consists of sedentary animals which exist in the cracks owing to accident rather than to any adaptations, scanty and usually stunted growths of a very few species of hydroids, half a dozen solitary and colonial actinians, about as many Polyzoa, a few dark red or black colonial corals (Dendrophyllia) that shun the light, as well as a few tiny solitary corals, a vast number of little sponges with every kind of skeleton and of tiny colonies of encrusting tunicates, here and there little stony branching red skeletons of the foraminiferan Polytrema, a few tubicolous worms usually of small size, and finally odd pairs of alphaeid prawns, characterized by one large immense chela which snaps, its fellow quite tiny, sedentary because they here live in a matted tube of fine fibres.

The second fauna may be termed the sand feeders,

animals which obtain their nutrition by sending almost continuous streams of sand through their alimentary canals, this sand probably passing out of their bodies in a much finer state than that in which it entered. Holothurians and sea urchins belong here, but they have such strong methods of holding on that they can live in the open waters and need no protection. Some sea urchins are covered in the sand which they steadily pass through them, while others rasp off the growing surfaces of sedentary animals; some live quite in the open and obtain protection from the waves by wedging themselves by thick spines, and others possess elongated pointed and poisonous spines. The larger wandering holothurians are what the Chinese call trepang and use for soup, these often having little fish (Fierasfer) darting in and out of their cloacae; but in crevices under rocks and corals are many smaller and less coloured species, and there are a few Synapta as well, these characterized by their thin sticky skins, often variegated with every shade of colour, some of the most striking species up to 6 ft. in length by an inch thick but capable of any amount of expansion and contraction. Then in the sand accumulations are sipunculids, all easily recognizable and colourless. Thalassema is rare, but is always worthy of attention on account of its frequently gaudy coloration and by its peristaltic waves of contraction, giving rings of rounded swellings in the meshes between its longitudinal and transverse muscles. Lastly, various enteropneusts may be expected, Ptychodera, Spengelia, and so on, all colourless forms and all giving to the sand a peculiar iodoform smell, which is quite diagnostic of their presence, its use perhaps to keep other forms of life away out of their muddy sand.

The third fauna consists of animals which live in sand but do not feed upon it, such as polychaetes, often species

with highly objectionable spines, a few kinds of bivalves, nemerteans always scanty in numbers, but this the best site in which to find them, a few peculiar species of stomatopods usually in pairs, and finally any of the sand-living crustaceans, here more by accident than choice. Fourthly may be recorded the regular free-living animals of all kinds, the home especially characteristic of certain minute fish which enjoy a 'ménage à deux', certain short free-living chaetopods, some genera of chitons (Cryptoplax), and many crabs and prawns, some peculiarly flattened. Always difficult to collect in variety but here more diverse than elsewhere are the brittle stars, of which the species are few, the nudibranchs and the Turbellaria. Many of the latter groups are peculiar in possessing colorations of extraordinary brilliance, set in the most bizarre patterns, while often living in an environment of almost total darkness.

All the above forms tend to be associated together wherever carbonate of lime is being deposited by organisms in sufficient quantity to form shoals of some sort and necessarily may occur on coral reefs. The surface of the latter to seaward is so pounded by waves and incrusted by Lithothamnioneae that it is not favourable to the collector. There are, however, areas where dead coral colonies tend to be piled together, and there are usually beaches with beach sandstone formations that readily split off revealing crevices rich in life. Only the corals themselves, the various calcareous algae, and the fauna associated with the spaces between their living stems are more varied on actual coral reefs. Here the association of all animals is essentially based on the corals, which may consist of a regular tropical jungle of many species of coral anemones growing in great luxuriance inside a lagoon to little stunted growths on outer reefs, or to isolated colonies fighting the sand and

mud which trics to envelop them. These reef corals feed mainly by the help of their commensal algae, and therefore they are necessarily striving like plants to grow towards the light. Massive corals when they reach the surface die in the centre and grow outwards on the sides forming spreading masses. Plate-like forms grow outwards and upwards especially in crevices, and some are quite cup-like. Branching forms where exposed to the waves have broad tops formed of multitudes of small low stems of equal height, set on a central pedestal; staghorn species prefer to live where less exposed. Acropora (Madrepora) and some species of Montipora are the commonest branching forms, their skeletons perforate and hence presenting rather a sandy appearance when broken; many of the branches of the former have violet tips, this coloration as well as the green due to the algae. Pocillopora is next in quantity among the branching species, its skeleton imperforate and much firmer and smoother with plates across its tiny tubes, its colonies never of great size but found everywhere, even in the heaviest waves, their colour green, light brown, and pink. Stylophora and branching Porites have more rounded stems, and often form round masses up to 3 ft. across, their bases bedded in sand. All these corals have small anemones, seldom more than 1·5 mm. across and so contracted into their cups, when removed from the water, as to make their whole colonies appear almost lifeless. The largest polyps are those of such genera as Mussa and Euphyllia up to 2 or 3 in. across, the former a rough and spiny skeleton, while of intermediate size are a whole host of astreids and other forms mostly of massive facies. Fungia lie about on the smooth underlying rock, and their minute strobilating fixed stages may be found at the bases of large corals or in crevices. Of massive forms Porites colonies may be

found up to 20 ft. or more across, dead in the centre and even hollowed out, with a living edge of polyps. Usually present are yellowish plate-like growths, very smooth and stinging, set in masses several feet across (Millepora), and the blue coral (Heliopora) has a similar form, its surface film of living tissues dark green. Then there are great masses of the leathery corals (Sarcophytum, Lobophytum, &c.), whose side growths flop about like pigs' ears, these sometimes living in quite muddy water, and occasional colonies of zoanthids and of Xenia, in places the latter almost covering the bottom. These latter show at once, even at low tide, their actinian affinities, all other forms having their polyps sunk in their skeletons, their tentacles all retracted. Towards low tide this retraction is usually the case, but on a dull day at high tide some colonies can be seen expanded, then presenting an appearance of rich and luxuriant life. It is not a matter of light and darkness alone, for they show little difference in day and night.

Next there are the free-living coral associates. There are on an average reef about two dozen species of tiny fish that never live anywhere save between the stems of the living and branching coral colonies, and there are at least as many more who are indifferent as to whether the corals are alive or not. Many of these fish are laterally flattened, the better to penetrate the spaces, and all are provided with markings, stripes, splashes, and iridescences that look extraordinarily conspicuous to the human watcher in the air, but which may appear quite otherwise, if viewed from below the surface of the water. It is amusing to see them darting in and out of the corals, pairs or small shoals after bits of broken up fish or other food, or to catch them on tiny hooks dipped in the ink of the cuttlefish, preferably dashed with some strong scent. There are twice as many kinds of little crabs and they too are much coloured;

Melia is never common, but it is peculiarly interesting as it carries about in its great claws a pair of small anemones, doubtless to make use of their stinging powers. A fauna of peculiar prawns and alphaeids, there is too, many quite civilized by being apparently paired for life. In addition, all forms of free-living animals, whether of the surface, or of the holes in the reef, may be found, but they prefer the semi-protected spaces at the bases of the corals and do not seek the living stems. Occasional caprellids, pycnogonids, and crinoids are visitors from deeper waters, where their association is with branching gorgonians and forms of similar growth.

As a last environment there is the estuarine shore, which has its own peculiar physical and chemical conditions, and which is very profoundly influenced by the generally luxuriant vegetation of the country behind. There is a tendency for great flats here, and for these flats, unless controlled by man, to be overgrown with mangroves, which ever march by their stilt-like roots further and further out into the water, holding up the mud. The mangroves above water have their own peculiar fauna of birds, insects, and even small mammals, while the mud beneath at low tide is the home of countless burrowing crabs (especially the fiddler crab, Gelasimus, with its one huge chela), bivalves and worms, while fish move up between their roots with the rising tide. Frequently excellent oysters grow on the roots and gastropods cling to them, but nothing eats the mangrove bark or bores into the wood. The mud itself is usually stinking and has strong tanning properties, and how any animal can live is as difficult to understand as Arenicola and Echiuridae in the muds of our east coast estuaries. The species are few in number, and the interest is the study of what love it—and how they are adapted to it—and of what tolerate

it. The same species of Diogenes-like hermit crabs are found here as in every other environment, these scavengers being the least specialized animals in this respect.

The naturalist, having completed a reconnaissance of all the environments to be found on his tropical shore and having perhaps spent a week thereon, is now in the position to undertake the job for which he has come and to collect and observe for his own satisfaction. Let him once and for all understand that the scientific day is passed for miscellaneous collections of all forms of life, merely to record the topographical distribution of marine organisms. Such collections will not be welcomed in museums, and most of them will simply be allowed to rot, unless they have attached to them notes, as to how and where the separate beasts lived, of such excellence as to attract systematists. These notes to be so characterized may have to comprise the date and time of collection, the nature of the environment, the temperatures of the water and sand, the exposure to sunlight, the salinity and alkalinity or acidity (*p*H) of the water, &c., while the dates of new moons may be mentioned, since it is clear that many marine animals shed their generative organs according to a certain lunar periodicity. Many of such observations savour of pure research on individual animals or associations of such, and this is so true that we would only add, for the encouragement of acquisitive naturalists, that any exhaustive collection of any phylum of organisms is of great and permanent value to science, especially if date, locality, depth, and nature of the bottom is recorded on each label.

The equipment for collecting on the shore is of the simplest character, a knapsack full of corked tubes of different sizes and with two pockets for full and empty

tubes, a little vial of neutral formic aldehyde, so that preserving fluids for delicate specimens may be made on the spot by pouring a few drops on to the beast, when it is in a tube of sea-water; Bouin's fluid is also most valuable. In the belt is a sheath knife, one or two pairs of strong forceps and of course a hammer, and in the hand a light crowbar of fine steel, with one end clawed and the other chiselled, used to turn over masses of rock and to delve into holes. Bone forceps are often most useful. On open shores the naturalist will bring his (native) boy with him, providing him with a bucket or two and some form of hand net or other. As soon as all vessels are filled up with animals and plants, go home and at once sort the bucket into three or more enamelled basins—coloured are often preferable to white—filling up with fresh sea-water. In any case, fill up one bucket tight with weed, decaying coral masses, &c., and treat it in the same way. Now pick out after an interval all that is visible, and on the weed left in each basin throw a handful of epsom salts and a fresh crop of animals will, in two or three hours, have revealed itself. The contents of the basins can be put together and may be further dosed and left overnight, but the organisms of this lot will be ready to disintegrate and must before bottling be well hardened in 90 per cent. alcohol. It is often advisable to bottle all the 'dirt' together, not sorting at the time, gradually decanting off the alcohol and adding fresh until the preserving fluid is of sufficient strength. The most hopeless looking material when narcotized often yields rare forms. Each bottle or tube must have its label in the fluid, the carbon duplicate of which remains in the book.

Many of the organisms whose skeletons were found on our exposed beach may not be secured, or the coast may be so entirely unsuitable to such collecting that other

means may have to be devised.[1] Such means entail various forms of nets, dredges, and swabs, but there is perhaps no tropical land where these may not be made on the spot and as cheaply as at home. The natives in every part of the world use seine nets and in most weighted nets, cast from the shoulder; these are indispensable methods of collecting fish and all free-living swimming animals. If small forms are desired, baby seines of mosquito netting may readily be run up with the needle, weighted with bits of stone and floated by any light dry wood in the absence of cork. The principle of stake nets may be developed, and natives too usually have some forms of movable traps. Heaps of stone and coral may be made on sandy flats, their tops six inches below the surface at low tide, and baited with pounded up crabs and dead fish remains; free-living animals, especially fish and crustaceans, after a few days find out such heaps, and all these will be found 'at home' at low tide. They are then all readily caught in a large basket of palm leaves, which is kept open by a few masses of branching corals; this is placed, mouth open, on the opposite end of the heap to that which the collector is turning over.

The strands of hempen ropes may be unravelled, to make swabs such as are used for drying up the decks of vessels. These, swung on to the bottom, with a few fathoms of rope to spare, over the stern of a vessel at anchor and swinging to the tide, if taken up and cleaned every twelve hours or so, will often bring up a great variety of organisms, pieces of rock with a couple of dozen kinds of animals attached or clinging to them, numerous crustaceans, starfishes, molluscs, worms, and other forms. A

[1] There is usually a rich fauna to be found attached to harbour or breakwater piles, and harbourmasters are usually sympathetic to their investigation, while their men will often for a few coins pull up the suspended chains of moorings; note the period since their last cleaning.

swab or a dredge may be dropped out from the ship or shore as far as the length of warp will allow and hauled in. The dredge had better be, for such hand work, rectangular or triangular, its swords not more than 18 in. long by $2\frac{1}{2}$ in. across, set at angles of about 30°; each sword has to be perforated at its thick edge for the attachment of the net, which may be of cord of about as small mesh as the local netter can manage. In all cases where rock material is thus obtained, it should be anaesthetized for boring worms and hidden organisms. A pair of plankton nets floating out from the ship at the same time, in one-third and two-thirds of the depth of the anchorage, will indicate the floating fauna, on which the animals of the bottom so largely feed. When the anchor is raised, mud or sand is often found clinging to it, and a good sample should certainly be secured and dried, after putting any living organisms that may be found into some preserving fluid. A preliminary washing in fresh water and treatment with a little weak spirit, which otherwise would have been cast away, will prevent any objectionable smell from the sand when in process of drying.

Our naturalist will doubtless visit and search every possible habitat. If he is studying some particular groups or phyla of animals, he will be adopting a converse method to the author by considering his animals from the point of their structure, thinking out what kinds of bottom and of conditions are suited to them and so should be sought. Thus Amphioxus of different genera all live in sand, but such sand must be clean (sharp, as it is termed) and preferably in such a position that it is slightly stirred at every rise and fall of tide. If present, Amphioxus is generally local, but where it occurs it is enormously abundant. Large numbers may be readily obtained by sifting the sand through one or a series of copper-bottomed sieves of

different mesh, fitted into one another; these are held, while being shaken, just submerged in the sea-water, and this method is one which may also be used for all small sand and mud-loving animals. Equally sand loving are the enteropneusts, but they prefer either rather dirty sand flats into which they burrow (throwing up great 'mole' hills of the sand which has passed through their bodies) or shallow accumulations of sand under stones and living corals; their iodoform smell has already been mentioned. The author's recipe for these and all sand-loving animals is to find a flat of sand with rock a foot or two below. The collector will see at once if there are any mounds or sand-castings, and he will probably dig with success, using shovel or spade, while, if the sand is deep, he would follow his animals' burrows until he himself is submerged. After capture the enteropneusts should be kept in the shade in basins of sea-water, changed every three or four hours, until, by next day, they have shed the sand of which their bodies were full. They will then be killed and hardened and got into preserving fluid. The latter, whatever is used, must be subsequently changed at least twice, since these beasts possess in their bodies some substances, which in the tropical heat acts on the usual preservatives tending to decompose them, their own bodies disintegrating at the same time.

Worms (spiny Chaetopoda, Echiuroidea and Sipunculoidea) are found in still, muddy sand, and the mounds of many sipunculoids are difficult to distinguish from those of enteropneusts. Tunnel living stomatopods, such as the large Lysiosquilla, may also be occasionally dug. In addition there are many Chaetopoda which form tubes on rocks and in sand, and members of this order and of the Sipunculoidea are among the most important of boring organisms. Polychaete worms need handling with special

care to secure as many unbroken specimens as possible; the head in all cases must be present. The slender thread-like Drilonereidae are not uncommon but break up into separate segments. Forms in coral can only be extracted after narcotization. Amphinomidae, large forms with white bristles, which in the fingers cause sores, should be handled with forceps and never bottled with soft bodied animals. The outsides of echinoderms should be examined for polynoids, short scaled worms coloured as their hosts. The bug-like Myzostoma lives on crinoids. The adult Bispira with its double spiral plumes has the mouth of its tube level with the surface of Porites or is in the stem of a branching coral; it is not to be confused with the proso-branch Vermetus, which has a transparent brown or pinkish tube. The tubes of many sabellids and terebellids are inconspicuous, level with the surface of the rock.

There is no royal road to collecting, save only work. It is well to half fill a boat with masses of rotten calcareous rocks and of dead and living corals. Then, when the rise of the tide makes further work in the sea impossible, sit down with hammer, chisels, and bone forceps and break up these masses into fragments, carefully chipping out each animal. Any promising pieces may be thrown into a bucket and left for the night, and all free-moving animals will soon get starved for oxygen and come out. Around will be a circle of basins, for the catch will be a varied one. There will be Crustacea and Mollusca of all kinds, a few small fish, some flatworms (Turbellaria), and an odd nemertean perchance, all living in the crannies of the rock masses; a few sedentary animals will also be picked off, and good samples of these should be put in tubes at once, for species and colonies are difficult to sort apart subsequently, especially from this environment of stunted growths. Then in the rock or coral itself will be

more crustaceans, such as Hapalocarcinus and Cryptochirus, which have been grown over by the coral, and fleshy barnacles. There are also true borers, multitudes of worms, molluscs such as the 'date stone' (Lithodomus) and a few gastropods, masses of brown boring sponges, and many more animals of odd groups, such as octopods, or cuttle-fish, which have annexed convenient spaces; large forms of the latter live in holes in the reef rock, from which they are hooked out with difficulty.

Of other free-living animals there are the sea spiders or Pycnogonida, which should be placed in small tubes of strong spirit, not more than two or three together. They crawl on the fine branches and stems of weeds, hydroids, and especially Polyzoa. The Turbellaria dwell mainly on the under surfaces of stones, crawling between the sedentary sea-squirts (Tunicata) and taking refuge in any hollows of the rocks. Most are small, but Pseudoceros is sometimes six inches in length. Each can be induced to creep into a clean tube held under the water against the surface of the stone; by this means they can be brought in alive, for, in the present state of our knowledge, coloured drawings of these animals are necessary. Their preservation is always difficult as they tend to crinkle up, but a few drops of formic aldehyde poured into each tube, which should not have more than one animal, is as good as anything. The same remarks apply to the nudibranch, Chromodoris, which has been best preserved by being made to crawl on to wet paper, which is then plunged into a fixative; this method should be developed for Turbellaria and means might be found for keeping them flat. Bottom living Foraminifera can be seen creeping up the glass sides of any tumbler or beaker, into which some clean sand from below tide level has been placed. We know little of their life histories even in temperate seas,

and tropical forms are mainly of interest for comparison of their shells with those in various elevated rocks; we get their shells in sand samples, which we have probably dried for more general purposes. Of insects we may mention the bug, Halobates, often found on rock pools, though a wanderer over all tropical oceans; its eggs and larvae are found on floating cuttle bones and pumice, frequently being confused with young barnacles. Needless to say any insects which creep down into salt water, or live in brackish water marshes, should be carefully collected and preserved in 70 per cent. alcohol. Lastly, we have snakes (Hydrus), dangerous pit vipers, but withal timid beasts, incapable of harm so long as the body is covered and the thin parts of the hands are kept well above the surface of the water. They must not be confused with the smaller eels of the coral reefs, of which there are about half a dozen forms, some mottled.

Of sedentary animals we might make a catalogue of hydroids, Alcyonaria, anemones, corals, tunicates, Polyzoa, and sponges, and remark that pieces placed in 70 per cent. alcohol, if possible anaesthetized and expanded, with small slips both in 90 per cent. alcohol and in 4 per cent. formic aldehyde, are likely to be useful to specialists. We are, however, beset with difficulties at every turn in respect to the determination of the species of these forms. They have for the most part floating eggs or larvae or young, which can be carried by ocean currents over wide stretches of sea, and accordingly present little variation of species over each of our two great tropical oceans, the Atlantic and Indo-Pacific. Let the naturalist collect a few species only, but let him study the growth of these few carefully on the spot in relation to their environment, its detailed topography, the incidence of the sun's rays, the amount of the currents, and how far the water is clean and

carries plankton and land detritus, &c. It does not matter whether he knows at the time the names of his genera and species or not, for really intensive scientific studies of tropical sedentary animals have never yet been made. He will have the interest of knowing that he is adding something of high permanent value to biological science and he will be undertaking a study, the interest in which grows as the work continues.[1]

Research Problems of Tropical Shores

The dedication of the altar of science is to 'the unknown god'. This implies that the devotee has made acquaintance with what has been revealed and is willing to see what lies obviously in his field of vision. How has the shore and the submarine slope off it been formed? The contour of the land should be carefully noted, particularly its valleys and slopes, since the underlying rock of the sea floor is bound to be correlated with that of which the land is composed, masked probably by a superficial deposit of sand or mud. How far the scenery is due to rain, wind, heat and cold will give a clue to the antiquity of the land. If it is recent volcanic country, the steep slope, which commences off nearly all lands at about 50 fathoms and extends down to about 150 fathoms, will be convex; if it is ancient or its slope due to coralline agencies, it will be concave. The 'steep' may have been directly or indirectly

[1] The statements made in this section are largely based on the author's experience in the Indo-Pacific, but have been checked by Mr. F. A. Potts, and more particularly by Dr. Cyril Crossland. Exceptions to nearly every fact of topographical distribution could be given, for instance localities where the naturalist can wade through gorgonians with their associated crinoids, or through thick masses of attached Sargassum, or over reefs where corals are almost non-existent. As to the West Indies, almost every paragraph requires some punctuation by exceptions, the oecological conditions of this region being clearly different from those of any part of the Indo-Pacific; this matters less as it possesses an abundant literature, mostly emanating from the United States.

due to faulting, and the land-slope down to it may have once been part of the land, absolutely cut out of it or separated by a coast line due to faulting, tilting, or slipping.[1] This area may have been extended, or be extending, further and further seaward by land sediments or coral growths, or alternatively perhaps be washing away. The earth has by no means an unbreakable crust, but the latter has a fluid layer beneath it, and its vertical position is influenced by alterations in the weights that overlie it, and perpetually recurring elevations and subsidences are patent to any traveller in most tropical island groups. These observations give the key to the land slope, and it is essential to hold this key, if the secrets of geographical distribution are to be unlocked, this also being an essential primary consideration in the study of the organisms of any particular shore environment.

The ocean is one mass of salt water, not a series of isolated masses. Its organisms either in the egg, young, or adult condition have the widest powers of dispersal. Nearly all groups of them are of inconceivable antiquity, and isolations affected by land—the Indian Ocean was open to the Atlantic in the cretaceous period and the latter to the Pacific in the miocene—are quite recent as compared with the aeons of their existence. There are polar, temperate, and tropical areas separated by temperatures, with certain species of organisms apparently peculiar to each. There are the east and west coast areas of continents, supposed to be characterized respectively by being warm and cold water areas, and by having reef growths and almost bare shores. The western tropical coasts are partly regions, where the counter equatorial

[1] The possibility of the floating apart of continents and islands (Wegener's hypothesis) need not concern us; the explanation of the facts of geographical distrbution of organisms does not require any such theory.

currents of great heat approach the shore; a full investigation of the whole biology (fauna, flora, physical, and chemical conditions) of one of these regions would be of great value, preferably the north-west coast of South America, comparison being possible with the relatively well-known fauna and flora of the West Indies. The slope off Walfisch Bay would be of interest in connexion with the faunistic work of the Fisheries Survey of South Africa. There is a belt of relatively cool water across the bay of Aden causing an isolation of the Red Sea, an area extraordinarily rich in life and reefs; this is in contrast to the shores of Somaliland, of South Arabia, and the whole Persian Gulf, while the west shores of India and Malay would seem to be richer than the east. Why does the reef growth on the east side of Africa stop long before the Mozambique Channel is reached? Can it be only temperature here with the warm Agulhas current constantly flowing down from the north after crossing the hottest of the oceans? Assuming that these statements are correct—and we have not precise facts enough to be certain that they are—can we believe that temperature is the main factor, while the brethren of the same organisms are quite tolerant of great ranges of temperature in temperate seas? The best-known case, that of corals requiring a temperature of at least 20° C., seems to us to require definite investigations, not only by inquiries as to the conditions where these animals occur, but also by experimentation, especially since their chief assistants as reef builders (Lithothamnioneae) live happily at lats. 60° N. and S. Why are there no reefs at Galapagos and off Panama, since, according to Dr. Crossland, Pocillopora, Porites, and other corals in smaller quantities, as well as Lithothamnioneae and Vermetus all live there? And why alone in the tropics are there dense shore algae off Galapagos? Are

there cold currents from north or south or an upwelling of deep cold water? We probably cannot answer the question about currents without the use of a ship, but we can attempt to determine such factors as are present in the water itself, and presumably govern the life, growth, and reproduction of our organisms.

Another distribution of marine organisms is by depth, and here the top zone is in connexion with the photosynthetic power of the sun's rays acting by means of chlorophyll. Marine plants, except phanerogams, will not grow on pure mud at any depth, but this is largely a question of the difficulty of attachment. In muddy waters the insufficiency of light prevents the growth of algae below 10 fathoms, while in clearer waters, especially off oceanic coral reefs, they may be found in vigorous growth at 30 fathoms, and apparently existing quite happily at 40 fathoms. The plankton is beyond our scope, but its importance is obvious so far as the nutrition of our beasts is concerned. First in importance, as probably in antiquity after the bacteria, are the flagellates, and these often cloud the sea near tropical continental shores, many not to be distinguished as animals or plants save by their green colouration, some conceivably at times with, and at others without, chlorophyll. Less coastal are the peridinians, and who can prove whether these are animals or plants, or an evolution independent of either of the main stems? Why do they swarm at times in incredible numbers? All we can say is that this is not meaningless, but whether it is correlated with unknown physical or chemical conditions or is possibly cyclical we cannot say. Similar causes probably affect many other organisms, directly or indirectly, and in many places any failure in the plankton organisms concerned would convert a shore luxuriant in animal life into a barren waste. Then there are the diatoms, less

numerous in species in the tropics than in temperate seas. They are in distribution some more coastal, some more oceanic, and some peculiar to each region. Quantitative studies of plankton show relatively few in the tropics, but occasionally their frustules are so numerous in the digestive cavities of such marine animals as do not presumably select their food, that the observer is inclined to doubt the present beliefs. The Radiolaria belong here; observations are required on every phase of their life-histories, on their reproduction and on their physiology. The author has never found Ciliates abundant in clear oceanic tropical waters, though often swarming in harbours or near city drainage. The initiatory phases of much of the work required belongs to the fixed laboratories of temperate zones, but the tropical naturalist can scarcely escape the considerations that are entailed in dealing with his shore fauna and can accept almost nothing as determined.

Below the light zone comes a mixed assemblage of all sorts of bottom animals feeding on the detritus of the organisms above and continuing downwards to 100 fathoms or more. It has often been referred to as a specialized fauna, but it commences at whatever depth the light-loving organisms cease to exist. Many of its organisms have been stated to be confined to specific depths, but continued research has increased the ranges of very many. The bottom in some places is so rough that a dredge or trawl can only be hauled for a few yards. Off continental shores it is often smooth and then hauls of even miles are possible; the contents of the bags then make widely scattered and rare animals appear common, and thus quite erroneous ideas arise as to the biological conditions of the area. Away from the land or reef the bottom becomes with depth progressively covered with smaller

sediments,[1] and this of course is supposed to inhibit the fixation of many sedentary animals, these being presumably absent from a continental 'steep', but certainly helpful in maintaining the similar 'steep' off coral reefs. The problem is largely that of Sir John Murray's mud line, but it is not a simple problem. There must be determined by observations, not by deductions, the physical and chemical conditions monthly for a year over whole sectors, from the shore to at least 200 fathoms, and the fauna at each depth station must be stated with accuracy, not only qualitatively but quantitatively as well. Trawling and dredging, while furnishing useful checks, are not accurate enough, and recourse must be had to Petersen's or other grabs of known area. These should throw a flood of light on the question of seasonal migrations in depth, and interesting comparisons will be possible with temperate regions, the quantity of life obtained being enumerated or otherwise measured.

The study of the food of marine animals in relation to the general economy of the sea can well fill up all intervals of time. The preservation of specimens for this purpose and the subsequent examination of their gut contents is of little use, because the gut contents are often ejected on preservation, or, if retained, so mass together as to be indeterminable; indications as to the food are often required on the spot, so as to enable any investigator of the continental slope to conduct his researches along reasonable lines. It is so evident that a study of the food of each group of animals is necessary that any selection by the author of special organisms for such research purposes is perhaps unwise. However, on tropical shores, especially in coral regions, boring and sand-feeding organisms may

[1] Considerable chemical activity may be visible in the deposits of this area as instanced by phosphatic concretions, glauconite casts, and manganese nodules.

play a conspicuous part in the formation of the coral mud. In coral skeletons the alga Achyla and the sponge Clione are of almost universal distribution, and these are succeeded in turn by numerous chaetopods, sipunculids, Lithodomus and other molluscs, and certain animals which enlarge the holes made by these. Many forms bore right up to the living polyps, and their advance is so rapid that they clearly have an efficient nutrition. The coral may be broken off, rolled about, killed, and so rotted that it is easily broken down into fragments, or it may be crushed up by flat-jawed fish, or rasped to pieces by sea-urchins and molluscs. Much of it is now in the condition in which it can be utilized by sand-feeding organisms, such as other sea-urchins, holothurians, sipunculids,[1] echiurids, enteropneusts, and chaetopods, most of whom show adaptations to this food in ciliated grooves or siphons in the digestive organs. How far is sand dissolved or rubbed down into mud when thus eaten? How much is consumed daily? What are the estimated numbers of these beasts in different areas? And what is their estimated effect? Why do some holothurians shed and regenerate their alimentary canals? Is there a regular autotomizing of the hind part of the trunk in enteropneusts? Or is this due merely to man's interference? What function does the iodoform smell of these last indicate? In the regions affected by sand feeders are many free-living animals, and their feeding is interesting too as well as their adaptations by swimming or otherwise so as to avoid burial. The feeding and keeping clean of sedentary animals are other

[1] This group is so little known that it would probably repay attention and be worth collecting thoroughly. In doing so a few nemerteans will be obtained, and we require knowledge as to the function of the proboscis of the Heteronemertea, the method of feeding and the food of all forms, and the method of contraction of the body down to 10 per cent. or less of the length of the living beasts, some of which are over 100 ft. long.

problems. How far do they select their food? Do they feed at particular times and is their feeding affected by light and darkness, rain, temperatures, &c.? Reef corals are a special case, in that they often have their body spaces crowded with commensal algae, in some anemones the stomodoea being completely closed. Do they take in solid food at all, or are they by this curious association practically holophytic? The latter might account for their limit in depth, viz. to the light zone, but not for the well-marked and numerous granular gland cells in their stomodoea and mesenterial filaments. What are the functions of the nematocysts which crowd these two organs? And lastly what are the especial characters which enable Millepora, Pavona, Pocillopora, and certain branching species of Porites to resist mud longer than all other forms? In all these observations the action of mud as a sediment and as an organ of rasping function, when being carried in suspension, must be carefully distinguished.

To recommend embryological problems is beyond our scope, but observations on the breeding of all organisms of our tropical shores are urgently needed. Are sedentary 'colonial' animals unisexual, protandrous, or protogynous? Do all forms ripen their eggs at fixed seasons or is the ripening merely correlated with food and growth? What is the actuating cause in bringing about the dehiscence of the eggs and sperm? How far do all forms of a species breed simultaneously even if in different environments? The advantage of doing so is obvious, but why does *Eunice* select a particular full moon for her operations and why do certain echinids exhibit similar phenomena? Where there are marked seasons, hot and cold, abundance and absence of food, much may be understood, but are marine forms of the tropics, which are not seasonal, more prolific than temperate forms? They are supposed to

grow faster, but the accurate measurements of their growth rates is worthy of attention. The setting of cleaned stones, piles, and floats is useful and may be undertaken especially in connexion with specialized embryological problems. Fishery authorities require a technique by means of which to determine the age of tropical fish. Lastly, how far do fish, crustacea, nudibranchs, &c., exhibit seasonal breeding migrations?

To the naturalist the little-known economy of the tropical organisms is so bewildering that his chief danger lies in a lack of concentration. He sees a vast variety of species, and no one form is so dominant as to compel attention. Probably three-quarters of the species of animals he brings home were caught in habitats other than those in which they flourish at their optima. Almost every sedentary beast he looks at has its associates, crabs and other crustacea with all, pycnogonids, caprellids and crinoids, ophiurids, fish, and crawling worms with most, occasional galls in the stems, &c. Holothurians have their fish, crabs, gastropods, and worms. Hermit crabs have their epizoanthus, hydroids, and anemones. Heteropsammia has its sipunculid. Can we be content with merely recording such associations without thinking how all concerned come together and may be affected? Then there are the wonderful colours of many forms. The fish of very shallow waters are most conspicuous, and explanations have been offered depending on the incidence of direct and reflected lights in relation to the environment, suggesting that they subserve certain functions of protection. Of what use is the extraordinary coloration of the mantle edges of Tridacna, or that of turbellarians and nudibranchs, so many of which live in darkness, and actively shun the light? But why go on further? An intensive study of the daily life of almost any living

animal will yield secrets valuable to science. Let the research worker see what interests him, and having selected his problem in relation to his own technical knowledge, let him pursue it to the exclusion of all else; he will, however, save time in the end by 'wasting' a few days in trying to visualize the interrelationships of his shore beasts, before he sets to work on his own more specific theme.

B.

CORAL REEFS AND ISLANDS

Islands divide themselves into three classes, continental, volcanic, and coralline, in accordance with the composition of their rocks, though it is not always easy to separate them. A continental island is one which, from the nature of its rocks, or more generally from the considerable variety of the animals and plants which live upon it, must be supposed to have been at one time connected with some continental mass of land, upon the surface of which, according to our present views, a large variety of animals and plants may be supposed to have been evolved. Thus, for example, all the greater islands of the East and West Indies must have been connected at one time with their neighbouring continents. There is little room for doubting (see Fig. 13) that Madagascar was at one time joined to Africa, and New Zealand to Asia and Australia through New Guinea; New Zealand may have had also a polar connexion with South America. The Seychelles Islands are formed of granite, a type of rock essentially associated with the immense early solidifications of eruptions which formed great continents. They doubtless were a part of the Indo-African Continent, which is

believed by many to have once extended between Africa and India—'Lemuria', as it is often termed.

The Fiji Archipelago is a more doubtful case; its rocks are of recent volcanic types, overlaid by 'soapstone', composed of submarine deposits formed largely by Foraminifera and raised limestones. Its fauna and flora, however, are, comparatively speaking, rich and varied, but it must always be remembered that the numbers of species of animals and plants on any ancient land vary proportionately to its size, temperature, varieties of environment and rainfall; the influences of each of these cannot, of course, be exactly stated. In the case of islands formed by submarine eruptions, their proximity to other lands, and the presence or absence of currents and winds, suitable for the transport of the seeds and germs of plants and animals, are of primary importance. Hawaii, Samoa, and Tahiti were probably formed by eruptions, and to some degree they illustrate the influence of distance and size already mentioned. Mauritius, Réunion, and Rodriguez are probably further examples; but the former may have been connected by intervening islands to the Seychelles, and so to continents; Rodriguez was partially formed by an upheaval of the sea floor. The Atlantic islands—the Canaries, Cape Verdes, and Azores—are probably all of recent volcanic origin, though some of them have been supposed to exist on part of the site of a continent once connecting South America to Africa.

It will be now clear that the importance of the study of islands to a large degree depends on the light which they throw on the existence of former continents—on the distribution of land and sea in past geological periods. An island may exist where we are practically certain that there was formerly continental land, but it by no means follows that the island was ever part of that continent, since it

may have been formed subsequently to the submergence of the continent. Yet it is in islands that we might expect to find our best evidence of the existence of former connecting land masses.

The interest of our third class of islands—coral islands—is again different, and lies in the question, how far do they indicate the sites of former land masses which have disappeared owing to subsidence or to other causes? Some

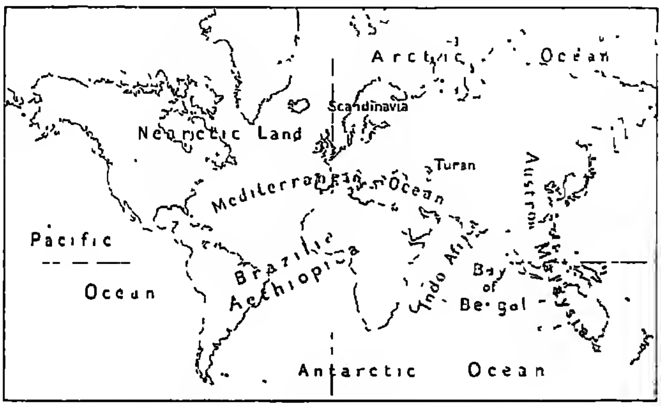


FIG. 13. Chart of the World, showing the supposed distribution of Land (dotted) in the Cretaceous Period

of these lands have been elevated to great heights, 1,000 feet or more, and are surrounded by reefs of a later formation. Such islands may be isolated, rising out of depths of 1,000 or 2,000 fathoms. Examples of these are Christmas Island in the Indian Ocean, Metia and some of the Pelews in the Pacific, and Bermuda in the Atlantic. All elevated 'coral' islands are not correctly so termed, for example Bermuda is formed of shell sand, the Bahamas of a kind of oolite, and Barbados of a comparatively deep sea ooze succeeded by miocene and pliocene deposits of medium depth. Indeed, there is much variation in the elevated limestones of the West Indies, while those of the Indo-

Pacific are largely composed of coralline rocks.[1] In Fiji high elevated coral islands are abundant, associated with volcanic islands and with landless coral reefs; every such island may have been formed by a separate and rapid upheaval, but Davis postulates a wave elevatory movement which affected the group. Many other islands, such as are ordinarily called 'coral islands', are quite low, rising only a few feet above the sea-level. They rest upon the surface of broad reefs, coral plateaux at the surface of the sea; and the method of formation of these coral reefs is the important question.

Coral reefs are found between lat. 30° N. and lat. 30° S., where the surface temperature of the sea does not fall below a minimum of about 20° C. Within these limits they exist in every land area of the Indo-Pacific Ocean, from the Red Sea to the Paumotuas, and, in addition, form a vast number of small isolated rings, most of which are crowned with land and garlanded with coconut palms. In the Atlantic they are found in the West Indies, off Florida, and in places off the coast of Brazil, but they do not form isolated peaks in the ocean bed or exist around its other islands, except Bermuda. Further, on the eastern shores of both oceans typical reefs do not exist, while on their western shores, as to the east of Africa and Australia, they attain great dimensions. Their shape and appearance wherever they exist is quite characteristic, a flat, almost level with the surface of the sea at low tide, on the seaward edge of which the ocean pounds down, even in the calmest weather, with great breaking waves. The water at low tide rushes over the flat for some distance, only to flow back by countless fissure-like channels in the edge of the reef. This area, the reef flat, as it is termed, is marked

[1] It is most important that biologists visiting such islands should attempt to obtain fossils upon which their geological age can be determined.

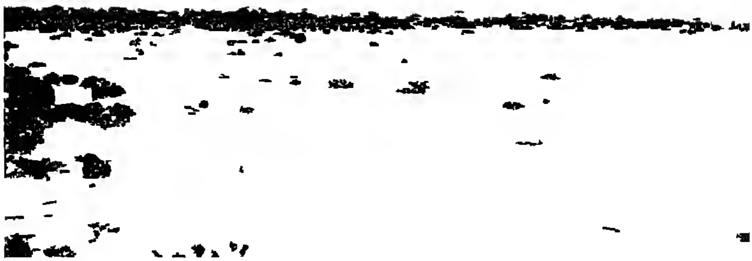


FIG. 14. Diego Garcia Atoll

Reef of east side at low tide looking seaward. Note boulder zone with inner (lagoon) and outer (reef) flats and line of breakers.

FIG. 15. Salomon Chagos

Buttress of Lithothamnion, North of Ile de la Passe

off on its inner side by a band of boulders, generally small masses of reef rock or coral colonies, which have been hurled up from inside or outside of the reef; hence is derived its name of the boulder zone. Instead of these boulders we may have a land, perchance formed by them, perchance of elevated coral rock, or of granite as in Seychelles, or of volcanic material. The reef here forms a narrow shelf around the land, being termed a fringing reef (see Fig. 16). Sometimes the land behind is separated from the boulder zone by a channel; this may be only a few feet in depth, when it is termed a boat channel, or it

FIG 16. Section of fringing reef, Rotuma Island, Pacific Ocean *a*, land; *b*, *b*, boat channel or lagoon flat; *c*, *c*, boulder zone, *d*, *d*, reef-flat, *e*, crest or edge of reef; *f*, *f*, seaward slope.

may be some fathoms deep, sufficient for a ship's anchorage, when it is commonly called a lagoon. To a considerable degree the depth of this lagoon depends on the distance of the land from the surface reef outside, but it seldom exceeds 50 fathoms. Inside of most reefs, within the boulder zone, there is almost invariably (if no island stands within the limits of this zone) a broad flat, with 1 or 2 feet of water at low tide, more or less covered with sand, part bare, part rich in coral growth. This is termed the lagoon flat, and may be the flat beneath our boat channel, or a flat before the water deepens to form the lagoon. Such a reef, with a deep lagoon within it around the land, is termed a barrier reef, but there is no sharp transition between it and the fringing reef.

Lastly, the reef may exist as an isolated structure by itself, with its reef flat, boulder zone, and lagoon flat. It

Fig. 17 St Joseph, Amirante Group

View of east shore of Pelican Island, showing five former beaches marked by beach sand stone, indicating pauses in the washing away of the land

may be (1) a small mass completely swept by the breakers; or (2) a larger reef with a mere pile of boulders in its centre; or (3) with the smallest puddle of water in a ring of boulders; or (4) with a great shallow lagoon flat a mile or more across; or, lastly, (5) with a lagoon flat and a deep lake, like the barrier reef lagoon above. In the latter

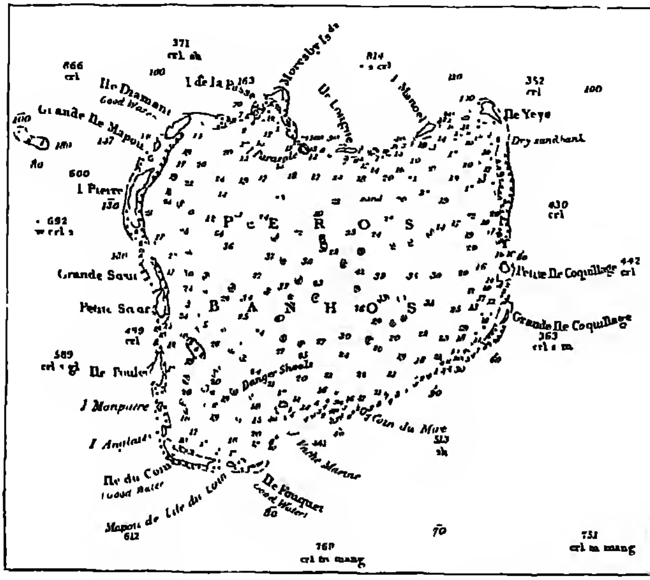


FIG. 18. A typical atoll; Peros Banhos, Chagos Group.
Scale, 4 millimetres = 1 mile

case it is termed an atoll (Fig. 18). Then it is essentially a ring of reef, bent as you will, surrounding a lake, the atoll lagoon, which may be a mere pool or a great enclosed sea 30 or 40 miles across), which, however, never attains a greater depth than 60 fathoms. A barrier reef may extend along a thousand or more miles of a continent's shore, as the Great Barrier Reef off Queensland, or, again, it may surround an island or a mere speck of land. Were the latter removed we would have an atoll, and the

Fig. 19. Peros Banhos Atoll, a boulder zone island of loose coral masses, consolidated and washing away to the left

Fig. 20. Egmont Atoll. Reef flat, coated by Lithothamnioneae and showing fissure-like channels (low spring tide)

obviousness of this fact was, pending the detailed examination of the reefs themselves, the cause of the prevalence for several decades of the single view that the ring-reefs were formed on the disappearance of the land which they once surrounded, first as fringing and later as barrier reefs.

Theories to account for the formation and origin of coral reefs centre on the atoll, since it is easy to see that any bold theory must be capable of explaining the formation of both barrier and atoll reefs. A caution may be at once issued to the effect that it is unlikely that any one theory will explain the formation and origin of all coral reefs. As to the formation of fringing reefs and isolated reef masses in shallow waters, there is no dispute, but to explain their building we require briefly to consider the organisms, the skeletons of which enter into their composition. It must not be forgotten that it is the biology of these which makes possible the formation of such reefs, and that we are not yet in the position to 'assume' these organisms, either in the present or in past ages, as Agassiz has done for the whole Indo-Pacific.

Coral reefs are formed principally of the limestone skeletons of animals and plants consolidated into rock mainly by sedentary organisms. Sand, formed from the skeletons of pelagic Foraminifera, or from the broken down shells of molluscs and echinoderms, or from the fronds of calcareous algae, always enters largely into their composition. In addition, there may be concretions of an oolitic appearance and muddy precipitations, for the sea may become supersaturated with calcium carbonate by a rise of its temperature, so that less carbon dioxide is held in solution, or by evaporation, or by the action of certain bacteria or of green plants, these using up the CO_2. In addition, there is much loose stone and sand material

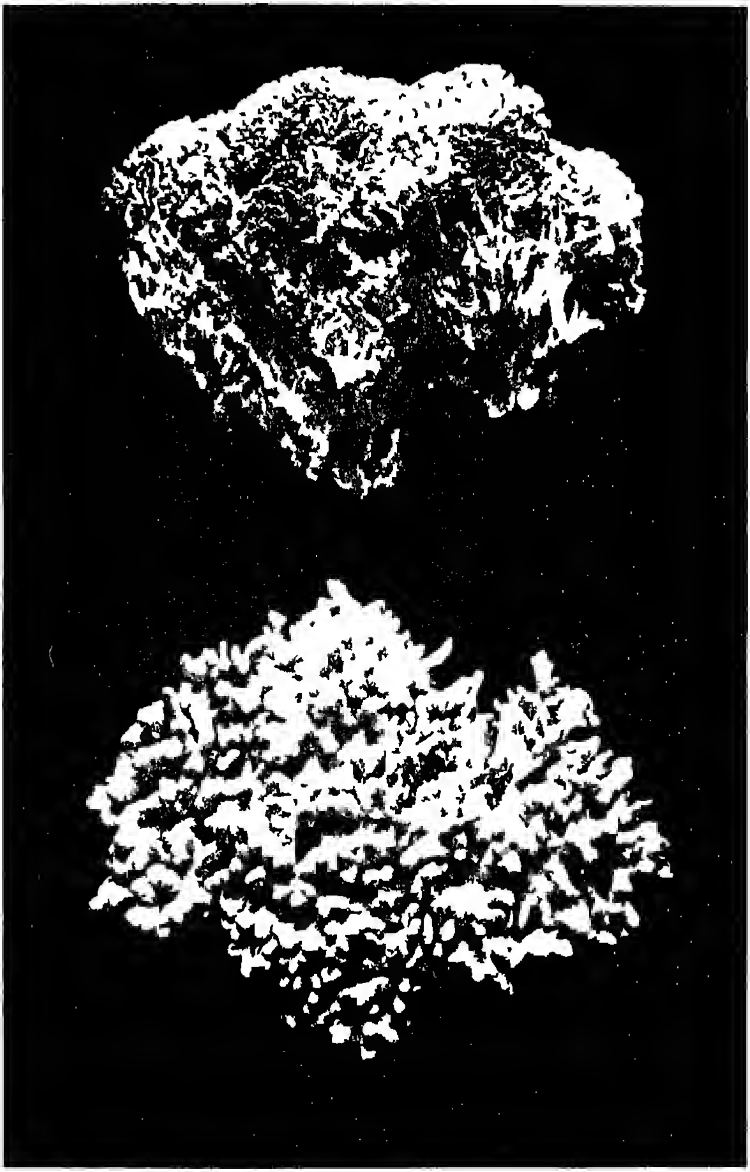


FIG 21 Lithothamnioneae upper figure, *Goniolithon frutescens*, lower figure, *Lithophyllum Gardineri*

formed by the decay and breaking up of corals and Lithothamnioneae, which are the great organisms in the consolidation of the whole into the rock that coats the surfaces of such shallow faces as are exposed to the force of the ocean. Any single ingredient may be found forming by itself a deposit, where conditions are suitable, but all kinds of organic remains enter into the composition of the massive barriers, upon which falls the full weight of the waves. Reefs in lagoons may have grown in protected situations and may consist mainly of corals, their interstices filled with sand, while the ocean rim may seem to have been built entirely by the red-brown incrustations of the Lithothamnioneae. In elevated coral rock these algal remains exhibit little structure and so are difficult to determine; the same remark applies to the remains of Halimeda and similar algae, the importance of which is much underestimated.

Corals, as the most widely distributed organisms in the formation of coral reefs, must first claim attention. The skeleton or corallum is mainly a deposit of carbonate of lime outside the ectoderm cells of the basal parts of anemones. These anemones have free floating planula stages, which in captivity have been known to live as such up to twenty-three days. They attach to hard objects and form anemones, which bud out other anemones from or near their mouth disks forming 'colonies', in which the digestive cavities of all the members still retain their connexions. With growth the deposition of corallum goes on until senile decay sets in, and the colony spreads sideways either by side budding, or by the intercalation of fresh mouths surrounded by tentacles as the surface becomes domed by the formation of skeleton. In this way great massive rounded corals are formed, quite commonly several tons in weight. In some forms surface areas of the

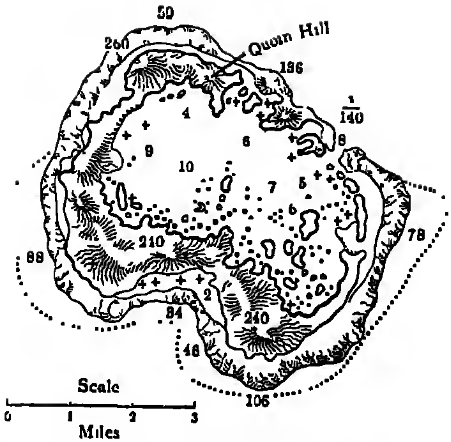


FIG 22 Fulanga, Fiji An elevated atoll raised at least to 260 ft. (Quoin Hill) The present reef has been formed subsequently to elevation and the lagoon has probably deepened All shores are cliffed

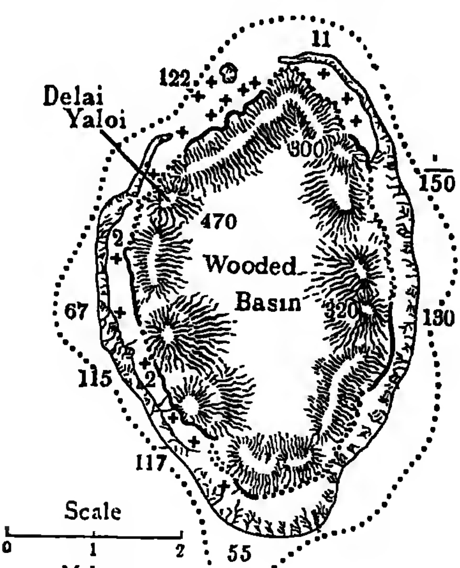


FIG 23 Kambara, Fiji An example of an elevated atoll, perforated in Delai Yaloi by a subsequent eruption of the volcanic foundations on which it was built Subsequent to elevation it has been clifted by sea action, and fringing reefs merging to barrier have been formed

quite small colonies are stimulated to growth so as to give rise to branched masses (Pocillopora, Stylophora, Montipora, &c.), or individual anemones may grow out in a similar manner, budding off side mouths (Acropora). In yet other species plates (Pavona) and cups (Turbinaria) may result, but Fungia with certain allies becomes free-living. The reef corals, which are a mixed assemblage of all these forms of growth, are classified into about forty genera of reef building importance, of which more than half are now confined to the Indo-Pacific region, about five genera being peculiar to the Atlantic. So far as can be seen the existing species of the reefs would appear to be of quite recent origin, most certainly not earlier than the pleistocene. They can withstand temperatures between 18° and 36° C. and salinities of 25 and 45 per mille, but exposure of an hour to the sun is usually fatal unless some part of their living tissues is still in the water. Mud they do not like, and off Seychelles all the corals were found to have been killed on a large area of reef after a heavy rain storm. Mayor for Samoa and the author for the Maldives have independently calculated that their rate of growth is such that they might by their own skeletons alone give rise respectively to reefs of 13·5 and 14·5 fathoms in 1,000 years, but the calculated rate for the West Indies is only a fraction of this. Recent work has confirmed Darwin in placing the extreme depth of flourishing banks of surface reef corals at 25 fathoms; the extreme limit of any of these forms is about twice this and the optimum depth for them as builders is 5 fathoms or less. Their feeding by commensal algae has already been referred to (p. 119), and experiments have been made showing that light is essential to them.

Corals, assisted perhaps by Millepora, Heliopora, Tubipora, and to some degree Gorgonaceae, Polytrema,

the alga Halimeda and sponges, may build reefs and indeed frequently do so in protected situations. Against the open ocean they cannot build in shallower depths than about 5 fathoms, unless consolidated by Lithothamnioneae, of which there are three important reef genera. These have fine branching species on sand flats, rounded nodules in passages through reefs, and massive attached growths on the seaward faces of reefs; they are not common lagoon forms. Their skeleton consists of about 74 per cent. of $CaCO_3$ and 15 per cent. of $MgCO_3$, while there is twice as much Mg as Ca in sea-water. The maximum depth at which these and other algae can live is about 55 fathoms. Their importance lies in the fact that they are more resistant to any change in the environment than corals, and their incrustations can resist the heaviest breakers, so that they always dominate the seaward parts of reefs. Here they are the chief agents by which reefs grow up to reach the surface and, when once there, spread outwards. In the Cape Verde Islands reefs have been described as formed solely of them and the tubes of Vermetus. Ordinarily on the outer edges of reefs little colonies of massive corals or of Pocillopora grow in hollows left by them, later to be incorporated into the solid mass. They spread out over channels, gullies, and pits and enclose them and their contents, leaving hollow spaces in the coral rock. The massive incrusting forms seem to like the rushing waters after the breakers crash; with increase in depth they become less important, coral largely taking their place, but this area to seaward is difficult to study on account of the surge and the roughness of the bottom, which prohibit dredging (Figs. 15, 20).

From the above paragraphs it will be clear how in seas of suitable temperature reefs may grow up on any shoal or round any land from a depth of 30 or 40 fathoms,

massive coral and algal structures with their interstices filled in with sand. The reef will be a flat on the surface, with the corals dead on the top or represented only by small colonies of poor growth. The sea will be surging up around, bringing abundant 'food' to its seaward face. The rollers will be constantly pounding down upon it and breaking off pieces, a few of which may be cast upon the surface of the reef to form a boulder zone, but most of which will be washed outwards to bring fresh areas within suitable depths for the reef builders. As this process continues, the reef will be spreading farther and farther seaward, broadening its surface, and making life less and less possible on its inner zone as the animals become more distant from their chief source of food-supply, the open waters of the ocean. This process may continue indefinitely, the rate of outward growth depending on the steepness of the outer slope of the ocean floor. The outgrowth must be assumed to result finally in the (almost universal) gradual slope for about 200 yards to about 40 fathoms, followed by the steep slope, often with an angle of over 30 degrees to about 140 fathoms. Further observations on the currents, bottom conditions, and fauna of the outer slope, are urgently needed. The steep is clearly a 'talus' formation, resulting from the outwash of loose masses of coral from the reef above, its angle of slope being the angle of rest of such rocks in comparatively calm water.

The theory of the formation of atoll and barrier reefs propounded by Charles Darwin in his 'Coral Reefs', a book of genius in its line as great as his 'Origin of Species', depends on the assumption that the land, round which a fringing reef has formed, is sinking at such a rate that the organisms upon the reef can, by their growth, keep it at the surface of the sea (Fig. 24). Such organisms will grow

more vigorously at the ocean edge of the reef, where they will have more food. Thus it will be easily understood that, as sinking proceeds, a channel (at first a boat channel, and then a lagoon) might be formed between the reef and the land. This lagoon will attain its breadth by the gradual submergence of more and more of the land, which finally might be completely lost, the formerly fringing reef becoming successively a barrier reef and an atoll reef, the contours of these roughly representing the former exten-

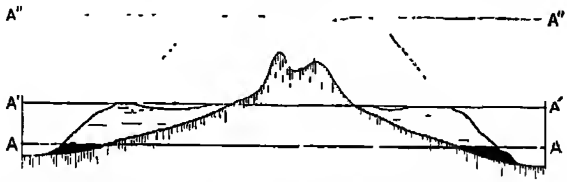


FIG. 24. Sectional diagram to illustrate formation of Atoll and Barrier Reefs by subsidence. A, A, sea-level of island, with fringing reef in black; A′, A′, the same after subsidence—island with barrier reef shaded; A″, A″, the same after the island has been submerged—atoll reef dotted. The vertical scale is many times the horizontal scale

sion of the land mass. It is a theory delightful in its simplicity, but it depends on the assumption that the land continues to submerge slowly for periods of time even geologically large. There are many objections to this premiss, and there is no evidence that such a general submergence is going on as would be required by the theory, i. e. from Africa across the East Indies to Hawaii and the Paumotuas. In this area many atolls arise precipitously from 1,000 to 2,500 fathoms, and, whether on this theory general or local sinkings are postulated, there should be similar thicknesses of coral rock.[1] There are

[1] It would possibly be an exceptional case where the added weight of coral formations would initiate the sinking of an island, but, if this were established, the constantly increasing mass of material, even if of relatively low specific gravity, might quite conceivably cause its continuance so as to give such thicknesses. The expected mounds and ridges of compensation are not known around

many elevated reefs in coral reef regions, and none show such vertical dimensions, the vast majority indeed being less than 300 ft. (50 fathoms) thick. Most are formed of very recent organisms, while such reefs as Darwin postulated might be expected to have been forming continuously through several geological periods. The elevations, which raised some coral reefs above sea level, were relatively rapid and conversely subsidences might be expected to have been similar. Furthermore, our knowledge of geology gives us no clear parallel to the slow and extensive bending or sinking of the earth's crust such as is required. In addition 60 fathoms is the maximum depth for the lagoons of atolls and barrier reefs—Vanua Mbalavu (Fig. 25) in the Fiji group alone showing a bight of 50 to 100 fathoms extending for several miles into a lagoon enclosed by a barrier reef—not a tenth of the sinking that must be postulated to form most atolls.

The subsidence view of the successive formation of barrier reefs and atolls is strongly opposed by all those who have in the last thirty or forty years devoted themselves to the biological examination of series of reefs, mention in particular being made of the late Sir John Murray, Professor A. Agassiz, and Professor Semper, who, in addition to having made explorations themselves, have had the benefit of the experience of numerous other expeditions. It has in the first place been shown that fringing reefs may owe much of their breadth to the abrasion of the land round which they form a belt. Tall cliffs and masses of rock, overhanging at their base, are often found bounding the shoreward edges of the reefs. The land in such a position is evidently being rapidly removed between tide-marks, and, as it recedes, it leaves

atolls, but the process of sinking would be so slow that ample time would be allowed for the dispersal of stresses over wide areas of the surrounding ocean.

at low-tide level a flat platform, indistinguishable from the shoreward part of a reef. If organisms commence to grow on the outer edge of such a platform, its surface appearance is in every respect that of a true reef (cp. Zanzibar and Pemba). This is especially the mode of formation

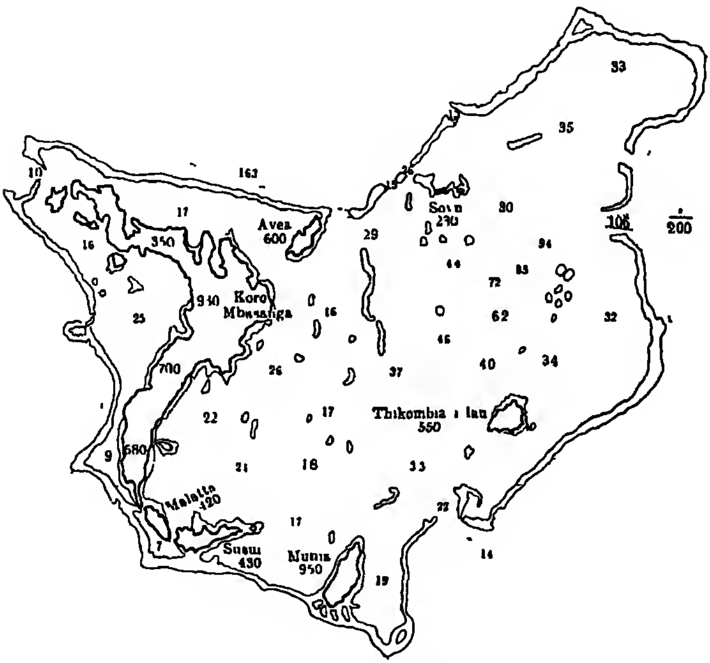


FIG 25 Vanua Mbalavu, Fiji The barrier reef is about 80 miles round The islands are formed of volcanic, or limestone or mixed rocks The elevation is at least 700 ft and the 100 fathom line extends deeply into the lagoon

where the land is composed of elevated coralline limestone, as is frequent in island groups where fringing and barrier reefs are abundant. Again, as a fringing reef broadens, neither the reef flat nor the boulder zone increase greatly in breadth, the inner part (boat channel or shore flat) broadening and taking up the extra breadth at their expense.

The shore or lagoon flat is obviously formed where once

was boulder zone, and it should therefore be strewn with boulders. On a broad fringing reef such loose masses are not found on the lagoon flat,[1] it being generally a bare or slightly hollowed-out area, which is alternately covered and uncovered by the tides. The latter must be the ultimate agents which effect the removal of the boulders, and this they are supposed to do by removing the coral, either in solution or as fine mud in suspension in the water, or by both means. The solvent action of sea-water on coralline material is relatively slight, but organisms are known to break up coral rock into fragments—gravel, fine sand, and, lastly, mud. The removal of material in suspension is evidently of great importance, hundreds of thousands of square miles of ocean floor near coral reefs being charted as covered with coral mud (see p. 265). How the latter is produced requires further investigation, but it is difficult to determine whether its fine particles were originally formed out of reef building organisms or are the result of precipitation.

By such methods as the above the inner rocks of the boulder zone might be removed, while the zone itself continues to extend outwards on to the reef flat as the reef grows seawards. It is easy to imagine the processes going further and hollowing out the inner part of the reef to form a boat channel and finally a lagoon. Should the reef start as a small mass in mid-ocean, it would pass through similar stages—a flat in the centre, then a shallow pool, and finally a lagoon. As a barrier the reef should in some degree conform to the contour of the land, but as an isolated reef it should be to a large extent more or less rounded in its early stages. Later, both the barrier and the

[1] Boulders formed of the skeletons of the blue coral, Heliopora, often persist for long periods of time, resisting most of the ordinary agencies which in such positions cause decay. The same is also true to some degree of Millepora.

atoll would show the effect of currents in carrying and depositing mud and other material, so as to make the extension of the reef in certain directions easier. From the first formation of any inner pool, channels would form through the boulder zone to allow the escape of the tidal water. The latter would especially rush out over the lowest parts of the encircling reef. Being charged with much sediment in suspension, it would kill any corals and other sedentary organisms in its path, and further would prevent any fresh corals from commencing to grow in its channels. Where dead rock occurs boring organisms enter, but where a surface, such as the seaward face of a reef, is covered with living tissues they cannot penetrate. The rock under a channel, being bare, will be bored and rotted like the rocks in the lagoon, with the result that its depths may increase more or less in proportion to that of the lagoon to which it gives entrance.[1]

Pending further research, it is quite impossible to say that this view of lagoon formation 'can be eliminated from further consideration', even though the solution of limestone postulated by Murray may not be the chief agent in the process. We know lagoons that are filling up and again others where the lagoons are as certainly growing, since their seaward faces are surrounded by small submarine cliffs, and the lagoon flats above the same appear to have been formed of exactly the same kinds of coral as are now found to seawards, cemented together by massive algal growths. Separate fragments of the land rocks have been found bedded in the coral rock, which forms the floor of boat channels, and, as already said, the whole

[1] Sometimes rounded growths of Lithothamnioneae are common in such a position. Often the sides of these channels are rich dredging-grounds for sedentary organisms, especially Gorgonians, Polytrema, and Hydrocorallines. Where the lagoon is large and there are several channels, this question of depth becomes complicated. It should be reinvestigated in each atoll.

question of the formation of coral mud requires investigation. On the other hand, there is no adequate explanation of the shallow depth of lagoons, even though boring and sand-feeding organisms become of decreased importance with increase of depth. We want sections across some atoll and barrier reefs with quite shallow borings, even 5 or 10 ft., with precise information as to what is building the reef to seaward, which must not be assumed to be growing outwards without direct evidence of the same.

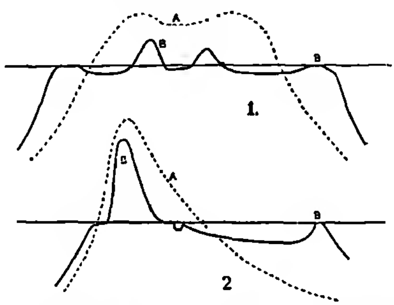


FIG. 26. Sections to show formation of Reefs by Abrasion of Land
1, Ongea Levu, Fiji, an elevated coral island; 2, Wakaya, Fiji, a volcanic island; A, supposed former sections of land; B, present sections of land and reef. The vertical scale is many times the horizontal

These should be reinforced with precise information as to the topography of the lagoon, as to the condition and composition of its lagoon flats and shoals, as to sand deposition (exemplified by samples), as to rates and nature of currents, with measurements of material carried in suspension in the same.

The last theory of the formation of lagoons offers no explanation to account for the submarine foundations on which atoll reefs are built up. It is conceivable that islands, which were originally surrounded by fringing reefs, may have been completely removed by abrasion and solution, the reef becoming successively of barrier and atoll type.

This mode of formation is seen in the Lau group of Fiji (Fig. 26), where the islands are mostly formed of raised limestone; but atoll formation by this means is probably not of wide occurrence. Secondly, an island may be cut down by the action of wind, waves, and ocean currents to form a submarine bank, no fringing reef forming while the process is taking place, owing to sediment produced by abrasion. On such a bank an atoll would be built up owing to the more rapid growth of suitable sedentary organisms on its rim, where they would be better nourished.

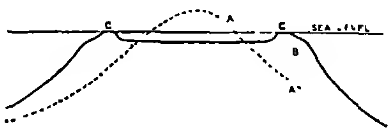


FIG. 27. Sectional diagram to illustrate formation of an Atoll on the site of an island of loose material which has been partly washed away; such an island as it is formed by a submarine eruption

A, original island; B, bank after the top of the island has been washed away to 20–50 fathoms; C, atoll formed by the direct and greater upgrowth of reef organisms on the edge of the bank. The vertical scale is many times the horizontal

Submarine eruptions may occur anywhere, and the contact of the molten lava with the water often produces a mound of cinders and ash, which may form an island or never appear above the surface of the sea (Fig. 27). Such a mound would rapidly be cut down to the limits of wind-wave action, even to 40 fathoms or more; on the bank an atoll would arise directly, in the way above suggested. Such a mound was Falcon Island, Tonga, erupted in 1883 to a height of about 250 ft., but later a submarine plateau covered by a few fathoms of water. Direct evidence of this method of formation of coral reef foundations has been obtained by the dredging of masses of semi-consolidated volcanic ash from 744 fathoms off Providence Reef, and Christmas Island on the other side of the Indian

Ocean would seem once to have been an atoll so formed. Vulcanism and coralline organisms are clearly to-day the great visible builders of land, and regions of elevated coralline limestone are areas of eruptive action. The lines of coral atolls in the Pacific almost irresistibly suggest themselves as being lines of vulcanism, and the topography of the many submerged shoals that are known, often called incipient atolls, is frequently explicable on this theory of the formation of their foundations.

Thirdly, mounds might be built up beneath the sea to suitable depths for the reef builders by the remains of various organisms. On any slight elevation on the ocean floor sedentary and other animals congregate to an extraordinary degree. Chief among these are the deep-sea corals, enormous banks of which have been discovered on the floor of the Atlantic by dredging and sounding expeditions. Their remains, assisted by the remains of pelagic organisms, build up the surface of any elevation to an extent out of all proportion to the upgrowth of the surrounding area of the ocean floor, so that the mound ultimately approaches the surface (Fig. 28). The reef builders obtain sway, and a reef soon reaches the surface, later to spread out on its own talus and to be hollowed out in its centre, forming a typical atoll. Atolls and banks built on such foundations, as postulated here and in the last method, should show some rounding off against and some extension in the direction of flow of the most constant currents which lave them, whereas the actual shapes of relatively few can be so correlated.

None of the above theories take full account either of the original mode of formation of the coast lines, or of the action of the sea on the same in periods of rest. Waves cut terraces into the land and build terraces, to continue the same further seaward. The movement of the

waters is largely responsible for the shelf, which extends to about 50 fathoms, before a steeper slope commences. This shelf is an area of great motion and of peculiar suitability to corals and calcareous algae, and to the consequent fauna attracted by them and by the abundance of algal food. Plenty of such shelves are known in temperate seas, and in some places sand banks are found on them parallel

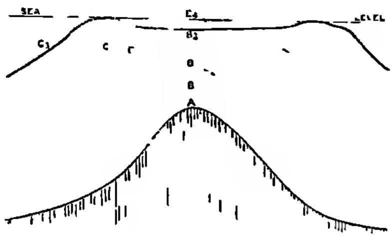


FIG 28 Sectional diagram to illustrate formation of an Atoll on a Mound of the Sea-Floor

A, original mound; B¹–B⁴, building up of same by remains of deep-sea animals, by pelagic deposits, and, lastly, by reef organisms to the sea-level, C¹–C³, outward extension by accumulation of talus and other materials on the slopes and further growth of reef organisms, hollowing out of the surface by solution and removal of mud in suspension

to the coasts. Were conditions on these to become suitable for coralline organisms, it would be easy to imagine the direct upward growth of barrier reefs, but on most shores the barrier would only be formed after passing through antecedent fringing reef conditions. Daly, who regards most existing coral reefs as still in the growth stage and as having been built on antecedent basement platforms either off land or as upstanding shoals, postulates such a slow continuous submergence of these as would allow of the direct upgrowth in their present forms of barrier and atoll reefs in general. This submergence is due to the recent melting of the great pleistocene ice caps that covered the two polar regions, even extending down into what are now temperate

latitudes. These caps were many thousand feet in thickness, and they further lowered the equatorial oceans by the attraction of their mass on the waters. The general lowering of temperature in the sea would prevent organisms protecting the sea faces of lands and the surfaces of shoals, and great submarine plains and terraces would be formed off them. As these polar ice caps melted, the conditions would become more suitable for the requisite reef building organisms, and all possible areas would become populated by corals and massive algae. As the water gradually flowed back from the poles, the growth of these organisms would keep the reefs they had formed level with the surface of the sea, the method of growth of the same being that postulated by Darwin in the formation of barrier reefs and atolls (Fig. 29).

At the present day in all tropical lands we see an emergence perhaps still in progress of 10 to 30 ft., but the pleistocene emergence and subsequent submergence of Daly is calculated to have been 200 to 250 ft. On emergence the sea would have been beating on mud and relatively loose material, not rocky coasts, and the formation of platforms would have been rapid. The fact that lagoons attain an average depth of 200 ft. agrees well. Many tropical lands in coral regions show some evidence of submergence, and this, not being represented in the topography of the surrounding ocean, is explained. So far as the biology of living organisms is concerned there would seem to be little objection to this theory, but to estimate its value as an explanation of the varied features of coral formations requires the comparative study of a series of tropical islands with barrier reefs. The same process of emergence and submergence has not taken place only in the Pleistocene and later, but in previous geological periods, and we require to know the relations of their

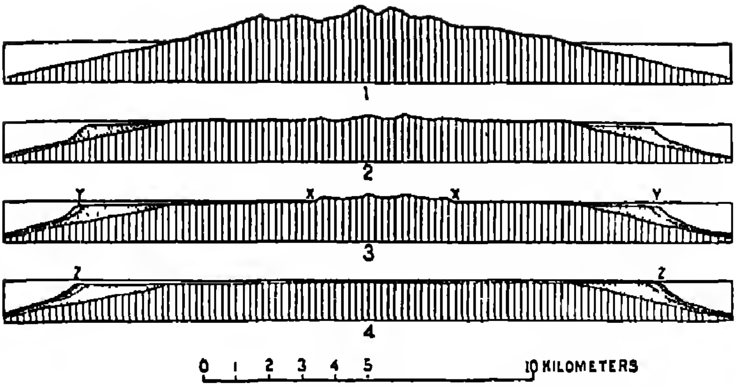


FIG. 29. Daly's sections to illustrate the development of Barrier Reefs and Atolls according to the glacial control theory

Section 1. A normal volcanic island.

Section 2. The same island largely peneplained, with the necessary formation of an encircling embankment of detritus (stippled).

Section 3. The same island extensively benched by waves, involving some increase of embankment. Such benching is expected in very old islands which have been exposed to active abrasion, either because of the Pleistocene chilling of the ocean, or because of temporary failure of reef protection in pre-Glacial times.

Section 4. Complete truncation of the same island by continued marine abrasion, with a slight broadening of the embankment. This is a stage that, in many instances, was possibly attained in pre-Glacial periods as well as during the Pleistocene.

In Sections 2, 3, and 4 the size of the embankment, as drawn, corresponds merely to the bulk of purely inorganic detritus. If intermixed reef and other organic material were allowed for, the embankment must be represented as broader. After the abrasion, the fringing, barrier, and atoll reefs would be favourably located at X, Y, Z, respectively. Shifts of sea-level are not shown.

The sections are drawn to scale and are also intended to show the great areal extent of the weak embankment materials, laid down around old oceanic volcanoes in pre-Glacial times. About half of the platform represented in Section 4 is underlain by these materials, which must have offered little resistance to the benching surf of the Pleistocene period.

coralline deposits. Is the surface of the earth so elastic as to allow of the removal of this water from the equator and its piling up in at least 1,000 fathoms thickness of ice at some parts of the poles without breaking and faulting beyond what we at present know? It is supposed that it may be, but we are as yet only laying the foundations of knowledge as to the history of the earth. We deal here with wide alterations of loads, but it has often seemed to the author that every alteration of load must be felt. The increased weight due to submarine erupted materials and to coral formations or even to glacial ice at the poles must be reflected in the earth's crust beneath it, and thus adjustment by sinking may help to a limited degree in the formation of both barrier and atoll reefs.

Having now briefly stated the chief theories of the formation of atoll and barrier reefs, it appears that widely divergent views are held as to their peculiar features. It will be particularly interesting if the traveller will note any parallel cases of barriers such as the sand banks, which frequently are found lying parallel to the neighbouring shores. Ring-shaped reefs forming parts of barrier and atoll reefs and similar shaped shoals within lagoons (faro)[1] deserve careful examination. Without direct examination it must not be assumed that either lagoon or any other shoals are growing upwards or that reefs in general are increasing to seaward, for according to Dr. Crossland such is not the case off Tahiti or Zanzibar. The one constant factor we have lies in our organisms, their reactions to different environments and their relations to one another. So far as we can see these reactions are not mightily different in our varied reef regions and 'therefore it is evident

[1] The word atoll is derived from the Maldivan word 'atolu', and we may as well borrow a second word from the same language, especially since these faro are a most important feature of the Maldivan coral region.

that the form of the reefs produced are not so much dependent upon the architectural design of the builders, as upon the form of the base they may have to build upon'. (Stutchbury, 1832.)[1]

[1] The above article was in type before publication of *The Coral Reef Problem*, by W. M. Davis. It is a most important and valuable study of all knowledge in respect to tropical coasts from a geographical standpoint. He maintains that the bays, large indentations and estuaries in such, if covered by reefs, merge into the land valleys at their heads. Where this is the case, they were clearly produced by subaerial degradation, and can only be explained by subsidence, or a positive movement of water-level.

All methods postulated above are possible, and each is probably partially correct for certain reefs. Reefs generally are growing surfacewards or laterally, or both, the organisms upon them accumulating heavy material as compared with water. This means alterations in the weight supported by the earth's crust beneath them, and it may well be that these are ultimately met by local depressions of the same. The alterations in weight are continuous, and such sinking might well be equally continuous (see Review, *Geogr. Journ.* lxxii, pp. 268–74, 1928).

Falcon Island (p. 143) has recently been in further eruption and a high island has again formed. The dimensions were 1,730 by 1,430 yds. by 305 ft. high (7 October, 1927).

IV

THE PLANTS

Floating Plants (Phytoplankton) and Borderland Forms

BY MARIE V. LEBOUR

PLANTS in the sea are represented by the seaweeds of the coast on the one hand, and on the other by an enormous number of floating microscopic forms. This floating flora is known as the phytoplankton. In the open sea, over any great depth, floating is the only means of living for the ordinary plant, as the sea bottom is too deep for any fixed form to live, light being a necessity for its feeding processes; therefore no plants exist on the ocean bottom and the only large seaweed found in the ocean is the floating Sargasso Weed described on page 188.

The study of the phytoplankton is thus the study of microscopic and unicellular plants. The chief groups represented are the Diatoms, Flagellates, Silico-flagellates, Coccolithophores, green algae and red algae, the two last with few species, but these may be enormously abundant. The groups mentioned are true plants, but there is another large group, the Dinoflagellates, which are usually regarded by botanists as plants and by zoologists as animals (see Chapter V). They are here regarded as on the borderland, for most certainly some of them are holophytic and others holozoic, that is to say, feed as true plants or true animals. Even the same individual may feed either as a plant or as an animal.

There are also large numbers of Bacteria in the sea. These are plants related to the fungi and are of an exceedingly simple kind. They are so small and require such special methods of study that they are here disregarded,

although they are of extreme importance in the economy of the sea.

All these form an enormous mass of available food for the sea animals, beginning with the unicellular species from dinoflagellates to infusorians throughout the Animal Kingdom, for the unicellular plankton serves as food sometimes for even large vertebrates. The plant[1] feeds by utilizing the salts and gases in the sea, breaking up carbon dioxide in the presence of sunlight by means of the colouring matter, chlorophyll or some closely related substance, contained in special bodies, the chromatophores, and so building up the complex protoplasm of which it is composed. It therefore occupies the base of the food chain, all animals being dependent on the plant, eating it either directly or indirectly. Thus a small sea animal eats the plant and is itself eaten by a larger animal, and so the great food cycle always goes on. The phytoplankton is sometimes aptly termed 'the meadows of the sea'.

Methods of Collecting. To collect these microscopic organisms special methods are necessary, although a pail or bottle dipped into the sea, and a sample of the water so obtained centifuged, will usually yield a fair amount of material. For the larger forms the same methods as those used for the small floating animals are applicable (see p. 230). A 'very fine' tow net (180 meshes to the inch) will catch a considerable quantity of diatoms, dinoflagellates, and flagellates, but the smaller species of these groups and practically all the coccolithophores and silicoflagellates usually escape through the meshes of the finest net. A water-bottle designed to fish at any depth is used in these cases (p. 59), and samples of the water thus secured filtered or centrifuged. The centrifuge is now usually

[1] The term plant is used here to indicate the typical plant which contains either chlorophyll or some closely related substance.

preferred to the filter. Those oceanic ascidians known as Salps and appendicularians (see p. 228) are extremely useful for securing very minute planktonic material as they feed by means of a fine natural filter which only admits very small organisms into the stomach. An examination of these may bring to light many rare or new forms. When examining the water-bottle samples by centrifuging, the best kind of tube to use is one drawn out to a thin blunt point, so that, after centrifuging, the superficial water may be poured away, leaving the required deposit at the bottom, which can be removed by a pipette and examined on a slide. There is nothing so good as examining such plankton alive. If preservation is necessary, however, formalin (5 per cent. solution) neutralized by borax is excellent, as it preserves the calcareous as well as the siliceous and cellulose skeletons. Fleming's Fluid, strong (see p. 400), 10 c.c. added to 250 c.c. of the sample, is exceedingly good for everything except the calcareous forms, and will preserve the shape of the delicate pelagic flagellates and naked dinoflagellates perfectly.

The Diatoms. The diatoms are unicellular algae with siliceous skeletons having brown or greenish-brown chromatophores containing substances closely related to chlorophyll. A typical diatom cell is formed like a box of two parts or valves, one fitting over the other, bound together by a girdle. Fig. 30, p. 153, shows one of the bottom forms with the typical diatom structure. This outer covering is formed chiefly of silica and is usually marked by pits or punctures arranged in exceedingly beautiful patterns. Inside is the protoplasm forming a thin lining layer and attached to the central mass by strands, the spaces between being full of a clear cell fluid. Embedded in the protoplasm are the chromatophores and nucleus. The individual cells may live singly or in

colonies. They are very variable in shape—round, oval, square, oblong, needle-like, hair-like, and may be twisted in various ways. All the planktonic diatoms are adapted in some way to a floating life. Thus if the cell live singly and be shaped like a disk or pill-box (Coscinodiscus), it is lightened by large masses of cell fluid of almost the same specific gravity as the sea-water and may

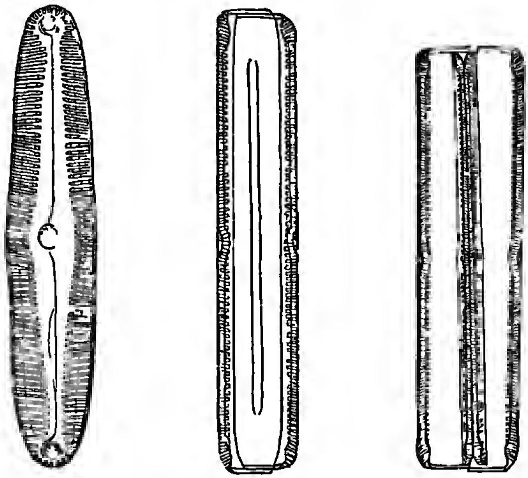


FIG 30 Pinnularia viridis × ca 500
a, valve view, *b*, girdle view, *c*, the new valve has forced the girdle apart

contain light fatty oils. Many disk-shaped forms are held together by means of protoplasmic threads (Thalassiosira), others may cling together by spines (Skeletonema, Fig. 32) or hooks, or by pads of protoplasm coming from special apertures. The large genus Chaetoceros (Fig. 33) has the corners of each cell drawn out into long setae which intertwine and form a large surface to prevent sinking. Bacteriastrum (Fig. 34) has similar spines all round the margin of the cell. Some may be in colonies embedded in a mass of protoplasm. Planktoniella (Fig. 31)

has a broad membrane all round the cell. All these are devices for keeping the organism in those upper layers of light, below which they must die. They are able to live as far down as about 200 m., but are more abundant above this, and it is found that in the ocean usually a maximum occurs at about 50 m. The planktonic forms generally have thin skeletons and the markings on them may be very faint compared with the bottom and littoral species.

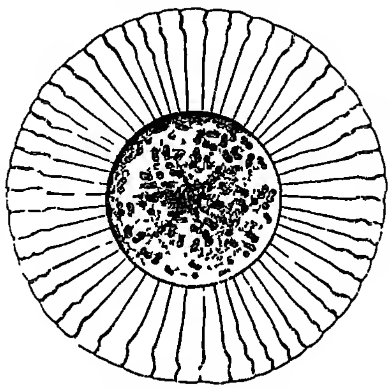


FIG. 31. Planktoniella × ca 500

Diatoms are by far the most important of the floating plants in the sea and may occur in enormous numbers, affording food for an innumerable quantity of animals. The fatty oils contained in them make them very nourishing, although so small. They may be found anywhere in the sea or fresh water, but the marine forms are usually more abundant near land. This is probably because much food is brought down by the rivers into the sea, and this is taken by the coastal diatoms, leaving little for those in the ocean. Oceanic diatoms flourish best where there is plenty of vertical circulation or ascending currents, when food which has accumulated below is brought to the upper layers. Nitrogen and phosphorus are probably the most

FIG. 32. Skeletomena × ca. 500

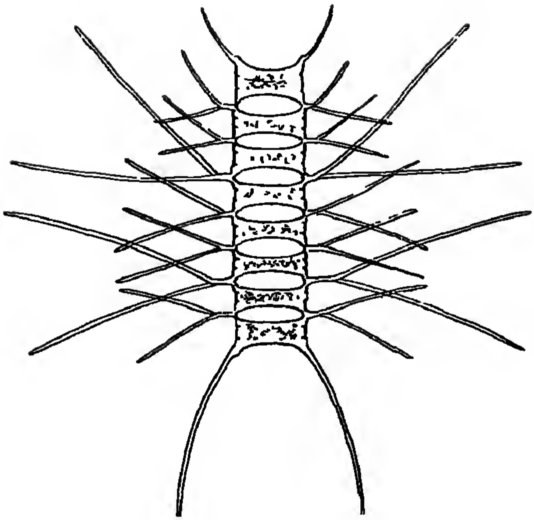


FIG. 33. Chaetoceros, from Plymouth Sound × ca. 200

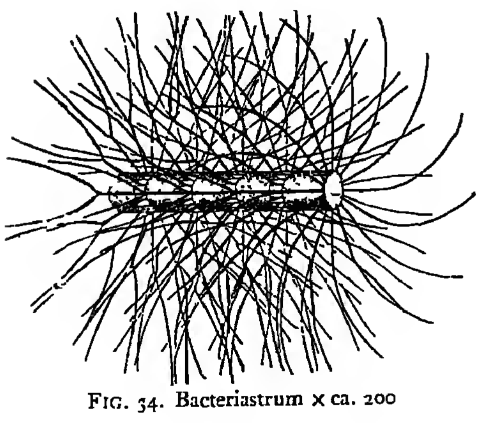


FIG. 34. Bacteriastrum × ca. 200

essential of their food-stuffs, silica next. They are usually more numerous and larger in cold and temperate climates than in hot regions and are never evenly distributed. Large areas may be free from them, whilst they abound elsewhere. Regular periods of maximum and minimum occur, in northern temperate regions there being two maxima, one in early spring and the other in autumn, each caused usually by different species.

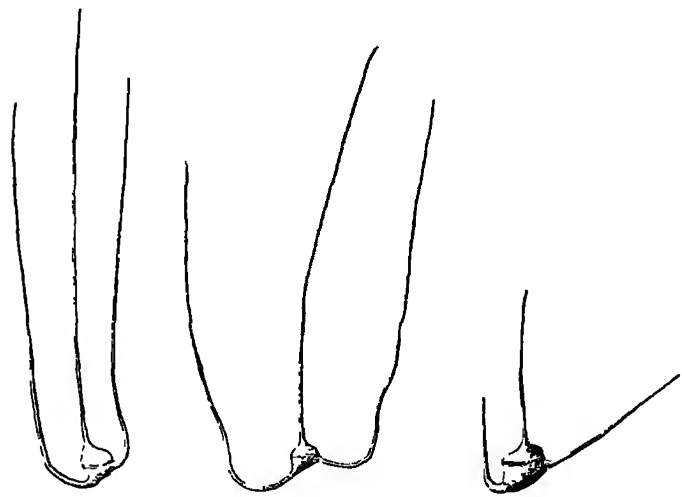


FIG. 35. Types of Ceratium × ca. 250

Diatoms reproduce by cell division, one new valve being added to each old one, or they may form auxospores, a large swollen mass of protoplasm bursting from the cell and forming new larger valves within. Spores have occasionally been observed. In adverse circumstances diatoms may form resting spores, which have hard coverings quite unlike the parent cell, sometimes of beautiful and peculiar form and often armed with spicules or spines. These when liberated from the parent sink to a lower level and are capable of great resistance and prolonged

inactivity. They are usually very minute and pass through the meshes of the finest net, but may be found by centrifuging the water samples, especially in coastal areas.

The Dinoflagellates. Next to the diatoms in importance come the dinoflagellates or peridinians. As already mentioned, these are on the borderland between plants and animals. Several well-known forms, some of which were formerly placed in separate groups, are included here. Amongst them are many brightly luminous organisms. Here we have Noctiluca (Fig. 83), which, although not the most important light-giving cell in the sea as was for some time supposed, still amongst the neritic species is very important in this respect. The different forms of Pyrocystis, perhaps the brightest of all, which light up the warmer seas to an enormous extent, are now known to be phases in the life-history of certain dinoflagellates, and no longer occupy a group to themselves. Ceratium (Fig. 35), the first and best-known genus, is also highly luminous.

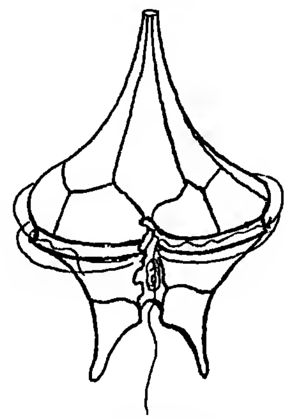


FIG. 36. Peridinium, from Plymouth Sound × ca. 300

Dinoflagellates are lovers of warmth and are to be found universally distributed, although more frequent in the warmer seasons, sometimes colouring the sea in large patches. They may be naked or provided with a covering or theca, composed of a substance related to cellulose, which is usually divided into plates. Typical forms have a groove running equatorially round the body, in which vibrates a whip-like thread, the flagellum (Fig. 36). A second flagellum is lodged in a less conspicuous longi-

tudinal groove and usually trails behind. In the naked forms the latter groove serves as a mouth which may engulf diatoms or its own relatives in a truly animal way. Noctiluca, which is the largest known dinoflagellate, may even eat small multicellular animals.

Many dinoflagellates are well adapted for life in the open sea, often having long drawn-out horns, spines, and membranes, which help to keep them afloat. They are almost always slightly asymmetrical, which helps them to adjust themselves easily and prevent sinking. Ornithocercus (Fig. 37) is extreme in having an enormous wing-like membrane, and this is perhaps the most truly oceanic of all. The genus Ceratium, with its three horns and anchor-like shape, is of world-wide distribution. Peridinium (Fig. 36) is also very widely distributed. Both Ceratium and Peridinium, with many others, are covered by a theca composed of plates arranged in a regular order.

The holophytic forms may have green, yellow, or brown chromatophores, and there are many colourless or with the plasma itself coloured pale pink or pale yellow, which have no chromatophores, and are probably saprophytic, living on decayed organic matter. All the species of Ceratium have yellow or brownish-yellow chromatophores, and some species of Peridinium and related genera also possess these, but many have none. The thecate forms are presumably holophytic or saprophytic, as their armature prevents the taking into the body of food of any size. It is quite possible, however, that many naked forms are phases in the life-history of these, and in such phases may be holozoic. The naked dinoflagellates may possess chromatophores, yellow, greenish, or brown, or may be colourless, or the plasma may be pink, yellow, or even crimson, purple, or blue. Those without chromatophores are usually holozoic, and engulf food as large or larger

than themselves. The chromatophore bearing forms may be either holozoic or holophytic, sometimes both. Those which are highly coloured are generally oceanic, and amongst them we find species which possess eyes with elaborate lenses and curious retractile prods coming from the longitudinal groove. Sometimes the body is twisted round the main axis, so that the grooves wind spirally

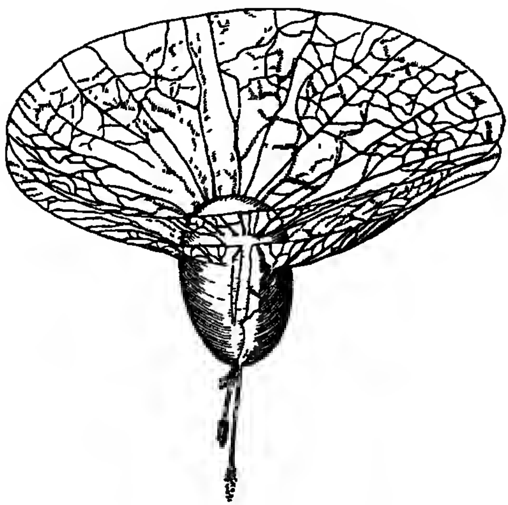


FIG. 37. Ornithocercus x 310

round the cell, which may be greatly elongated. Polykrikos seems to be well on the way towards the multicellular animals, for its cells, usually eight, hang together permanently and contain nematocysts, or stinging bodies, of a similar character to those belonging to the coelenterates.

Dinoflagellates usually reproduce by cell division. One or more spores may be formed in the thecate forms, the theca opening to set them free. The naked species generally divide obliquely, and so also does Ceratium, each side of the theca forming a new half. Newly divided cells often

hang together for some time, forming chains. Division appears always to take place at night. Complicated life-histories involving different phases of spore formation seem frequently to take place.

As food for other organisms the dinoflagellates may be individually even more valuable than the diatoms, although not so numerous, for their cell content is highly nutritious and the sizes of many of them far surpass the diatom. For those plankton-eating fishes, such as the pilchard, they form a regular food.

The Flagellates. Flagellates form an important part of the microplankton, but many of these are extremely minute and are very difficult to see in preserved material. Certain forms, such as Euglena, are claimed by the zoologist, and it is difficult or impossible to draw the line here between plants and animals. Many of the minute flagellate forms in the sea are probably spores of Foraminifera or other unicellular organisms. Those usually included in the phytoplankton have greenish-brown chromatophores and one or more flagella, or they may be colourless and possibly saprophytic. The most important of the flagellates in the sea is Phaeocystis (Fig. 38). This is a colonial form, frequently occurring in spherical, sausage-shaped, or large bulging shapeless masses of a gelatinous substance in which are embedded small greenish-brown cells. These masses appear periodically in enormous quantities, usually in coastal regions, and clog up any nets that may be fishing. Thus they are a great pest, both to collector and fisherman. Flagellated spores are formed inside these masses, which escape and swim away. There are other small species in this group, occurring singly or in colonies, perhaps the most important of these, although exceedingly minute, being Dinobryon, a branched colonial form. Euglenoid forms occur sparingly. A Euglenoid (Fig. 38*f*)

has a mouth from which protudes a flagellum or two, green chromatophores being usually present and a red stigma.

Green Algae Often classed with the flagellates, the only important planktonic member of the Green Algae is Halosphaera (Fig. 39). This occurs singly but is often very abundant, its bright green globules showing up con-

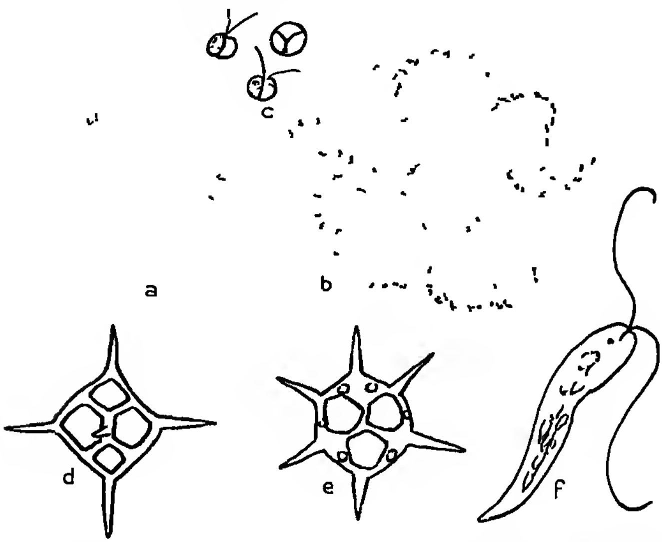


FIG 38 *a, b, c,* Phaeocystis *a,* spherical form × ca 48, *b,* large mass, *c,* swarm spores and resting spore × ca 1,000 *d,* Dictyocha × ca 400 *e,* Distephanus × ca 350 *f,* Euglenoid × ca 1,700 From Plymouth Sound

spicuously among the brown diatoms. It reproduces by flagellated moving spores and by resting spores, and being very light is usually to be found in the surface layers, although occasionally it lives in quite deep waters Several other minute relatives of Halosphaera occur, but are so small that they are frequently overlooked. Trochiscia is a spherical form bearing spines all round the cell, sometimes occurring in masses with the spines clinging together.

Silicoflagellates. Closely related to the flagellates,

several minute silicoflagellates occur in the plankton. As the name implies, these have skeletons of silica, variously shaped, the commonest having hexagonal (Distephanus), or four-rayed (Dictyocha) skeletons (Fig. 38 *d*, *e*). Inside is a mass of protoplasm containing yellow chromatophores and bearing a flagellum. When about to divide the skeleton becomes double.

Coccolithophores. This is a very interesting group of exceedingly minute organisms related to the flagellates and having calcareous skeletons composed of plates of the most wonderfully varied patterns. These plates were discovered on the ocean floor long before the live cells were known. Those of an oval shape were termed coccoliths and of a rod shape rhabdoliths. Sir John Murray discovered their real nature and succeeded in finding the live coccospheres and rhabdospheres, as they are now called, by allowing the water to stand in glasses in which were dipped fine silk threads to which the minute cells clung and could readily be examined. The protoplasm contains yellow or brownish-yellow chromatophores and there may be one flagellum or two. In the tiny Pontosphaera common in coastal water it is sometimes absent. The plates may be oval, round, rod-shaped, club-shaped, or even barrel-shaped and trumpet-shaped, sometimes sticking out from the cell like the heavy spines of a tropical sea-urchin (Fig. 40). They are sometimes pierced with holes as in Coccosphaera (Fig. 41), the best and earliest known species whose plates were first discovered on the Atlantic floor. This is common both in the ocean and in coastal waters and forms the food of many small animals. Rare species may be found inside Salps. The coccolithophores form an important, if minute, part of the oceanic plankton, where they frequently replace the diatoms and are some of the most beautiful of all unicellular organisms.

Blue-green Algae. There are not many members of this group in the plankton, but certain species may occur in enormous numbers so as to give a colour to the sea for miles, the so-called 'water bloom'. The cells are thread-

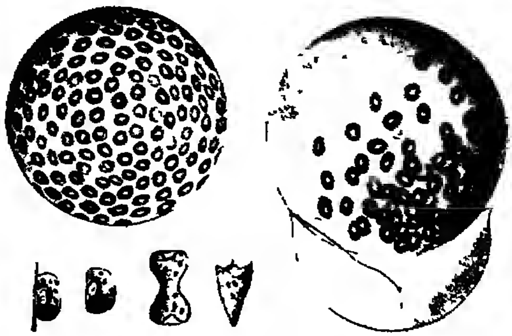


FIG. 39. Halosphaera × ca. 55

In the sphere on the left the protoplasm has gathered round the nuclei lining the wall; that on the right has shed the outer membrane, and the daughter cells have separated from the wall; below are four stages in the development of the zoospores

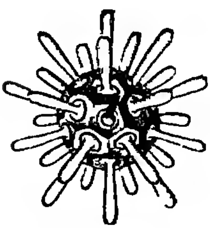


FIG. 40. Rhabdosphaera × 1,400

FIG. 41. Coccosphaera × 1,100

FIG. 42. Trichodesmium × 24

like and cling together in bundles (Fig. 42). Trichodesmium, which is reddish-brown, occurs periodically in the Red Sea in huge quantities. In tropical seas it sometimes spreads out for miles in large floating masses, and is occasionally to be found in temperate regions also.

All these minute organisms which make up the phytoplankton, together with those which may be regarded as

on the borderland between plants and animals, form a collection of living material always more or less present in the sea, never evenly distributed, but occurring at various depths and in various localities, their appearance and disappearance governed by laws which are being investigated continually and which ever produce new problems to solve. The importance of detailed notes on any group cannot be overestimated, and the microplankton, both animal and vegetable, offers a field for investigation where new organisms and new facts will be continually discovered.

IV (contd.)

Fixed Plants [1]

BY MRS. DR. A. WEBER-VAN BOSSE.

AFTER a storm heaps of plants are cast ashore by the sea, especially if the coast is rocky. On closer examination, these entangled masses are found to consist of green, brown, purple, or bright red plants.

What are these? Where do they live?

These bright-coloured plants are algae, or flowerless plants, distinguishable by their colour and various shapes from marine flowering plants; the latter have, as a rule, narrow, long, linear leaves of a dark green colour, as for instance the common sea grass, Zostera marina, so well known on English coasts. In various parts of the Mediterranean we find the sea grasses Cymodocea nodosa and Posidonia oceanica, while Zostera nana is the only marine flowering plant of the Caspian Sea. In the tropics the genera Thalassia, Halophila, and Enhalus will often form green belts along the coast mixed up with various algae.

But however interesting the study of the 'Sea Grasses' may have become since Ostenfeld published his paper on their geographical distribution,[2] this section treats only of attached or fixed marine algae. The mostly microscopical drifting algae, belonging to the plankton, have been dealt with in the previous pages.

A few words will be said of algae growing in brackish water, its interesting flora showing the influence of the changing medium; for some marine algae migrate through brackish water into fresh water, which has, besides, a rich flora of its own.

[1] The original drawings which illustrate this section were made under the author's direction by Mr. J. Obbes.

[2] Ostenfeld, On the Geographical Distribution of Sea Grasses, *Proceedings Roy. Soc. Victoria*, vol. xxvii, N.S., pt. 2, Melbourne, 1915.

Algae can assume the most different shapes; their fronds may be either simple or branched filaments (Chaetomorpha, Cladophora, Polysiphonia), or expanded membranes of various colours, composed of one or more layers of cells (Monostroma, Ulva, Porphyra); they may have the form of a smaller or larger bush with stem and branches (Splachnidium, Desmarestia, Delesseria); or look like a delicate bit of lace (Vanvoorstia, Claudea); or be composed of a long, flexible stalk, bearing long linear blades at its swollen top (Ecklonia buccinalis). Again, others form crusts, adhering closely to the substratum (Ralfsia, Hildenbrandtia), or have crust-like or ramified fronds entirely solidified with carbonate of lime (Lithothamnium, Corallina).

The diversity of their 'thallus' (as their fronds are usually called) is enormous; some are so small that they nearly escape our notice, and others so large that stem and leaves have a length of hundreds of feet. But however great their outward diversity may be, their inner structure is comparatively simple, and built up of either thin- or thick-walled cells. Nowhere do we find a differentiation of these cells into vascular bundles, as in flowering plants. Neither have algae any true roots that can be compared to the roots of flowering plants; their holdfasts are in many cases a few rootlets or a whorl of so-called hapteres; other algae fix themselves with a smaller or larger disk on the substratum, and algae growing in sandy bottom have long, hair-like, much-branched rootlets which fasten themselves to the grains of sand, and enclose so many of them that, when the plant is withdrawn from the sand, its rootlets present the appearance of a large lump.

Algae have various colours, and in accordance with these they are divided into:

1. Blue algae—Myxophyceae or Cyanophyceae.

2. Green algae—Chlorophyceae.
3. Brown algae—Phaeophyceae.
4. Red algae—Rhodophyceae or Florideae.

We must bear in mind, however, that, though this division is right in the main, there are many algae that do not show the colour of the group to which they belong. Blue algae living in deep water may become red; red algae may turn purple, brown-red, green, or even yellow, on being more or less exposed to the glare of the sun; but with a little practice the group to which a certain alga belongs is easily recognized; for differences of structure and fructification correspond with the differences of colour.

Algae are found on all coasts in both hemispheres if the outward conditions are favourable for their growth. We find them in the Arctic and Antarctic as well as in the tropics, forming a more or less well-defined belt along the coast. Some algae grow so high up that only the spray of the sea, as it is dashed upon the beach or against the rock, can reach them; others live in deeper water, from which only a dredge can bring them up. This belt of algae is divided into two regions: the littoral region, comprising that tract of the coast which lies dry at every ebb-tide; and the sublittoral region, comprising all vegetation below low-water mark. The algae of the littoral region are adapted to a period of exposure at every ebb, the algae of the sublittoral region to a continually submerged existence. Both the littoral and the sublittoral regions are again divided into an upper and a lower zone, according to the different algae found in each; for, though many algae have a wide distribution, yet almost every species has its own privileged locality in a vertical, as well as in a horizontal, direction.

In this connexion it will be worth the student's while

to study Cotton's 'Clare Island Survey', which gives an elaborate ecological and distributional survey of that island.

The internal organization and the external agencies determine the place a given alga will occupy. The external agencies are light, the nature of the bottom, the salinity of the water, the strength of the currents, &c. To understand their influence well, one has to study different localities, for agencies exercising a certain influence on the coast of Greenland will have an entirely different effect in the tropics, according to their different combination.

Light is the chief factor; every plant wants light to reduce the carbonic acid needed for its existence. Some algae may want more, others less; but without light no vegetation can exist. Different men of science have studied the problem of how far light penetrates in sea water; for the old method of lowering a white disk and registering the depth at which it was still visible, has long been felt to be unsatisfactory. Photo-electric cells are far more reliable, and Gail and Shelford published in 1922 the results of their observations made with the Kunz photo-electric cell on the penetration of light in the waters of the Puget Sound. They made their study with particular reference to the distribution of algae. Poole and Atkins carried on these studies in the English Channel near Plymouth by a telephone method of measuring photo-electric currents, which enables measurements of submarine illumination to be made in a small vessel by means of photo-electric cells. The description of the method and the apparatus must be studied in the elaborate papers of the authors.[1]

[1] H. H. Poole, On the Photo-Electric Measurement of Submarine Illumination: *Scient. Proc. R. Dublin Soc.*, 1925, vol. xviii, No. 9. H. H. Poole and W. R. G. Atkins, On the Penetration of Light into Sea Water: *Journ. of the Mar. Biol. Association, Plymouth*, 1926, vol. xiv, No. 1.

The results Poole and Atkins arrived at show some minor differences from the results Gail and Shelford obtained. Both found that the absorption coefficients of light are greater when the water contains much floating material. In Plymouth water the least loss is with a glassy sea and a grey sky, and in Puget Sound waters the maximum of photosynthesis takes place with a clear sky and smooth water.

In Puget Sound 35 m. depth is about the lower limit at which photosynthesis takes place. In the English Channel water with glassy surface transmits 0·54 per cent. of the vertical illumination to 34·8 m. The greatest depth at which encrusting calcareous algae were found in the Channel is 50 m. (Mme Lemoine).

Interesting as the results of Poole and Atkins are, we must not forget that their coefficients of absorption are found for northern seas. In tropical oceans with an almost ever clear sky, the illumination will be quite different, and a botanist may say 'I have found algae at a depth of 120 m. (Lithophyllum Philippi in the Mediterranean) and therefore some rays of light must penetrate so far'. But this actual limit gives us no idea of the quantity of light each alga needs to thrive well. Each alga has three limits with regard to light: an optimum, a maximum, and a minimum limit. The optimum limit is that degree of light in which a given alga thrives best; the maximum limit indicates the strongest; and the minimum limit the feeblest degree of light in which the same plant contrives to live. The four groups of algae just mentioned have different optima with regard to light. The blue and green algae live mostly in the upper part of the littoral region; the brown algae love the sunny places of the lower littoral and the upper part of the sublittoral region; and red algae are often found in the sublittoral region or in localities

sheltered by overhanging rocks or corals. But, true as this division may be in a very general way, there are many exceptions: some red algae can even live in places exposed to the glare of the sun on reefs in the tropics, though they loose their bright red colours in these exposed localities. Green alga again may go down to a depth of 100 m. (Dry Tortugas).

Each alga thrives best in the place of its optimum limit and will chiefly be found in it. If we study the alga belt of a given coast, we see that algae live in zones often overlapping one another, and that each zone has its own particular inhabitants. These vary in different parts of the world: in Iceland the zones consist of different algae from those of the coast of England or of France, not to mention the different vegetation in southern or tropical seas. Light is the chief factor in determining the place a given alga will occupy. But there remain still many puzzling facts and questions open to controversy. These cannot be treated here, for it would lead us too far. It may be mentioned that according to Lubimenko[1] each species of red algae may diminish or add to the total quantity of its pigments (Chlorophyll and Phycoerythrine), according to the depth of its habitat and that the proportion of Phycoerythrine is variable in the different species and becomes greater with the depth of the habitat.

Depth. When speaking of the penetration of light into sea-water, the depth at which some algae occur has already been mentioned. The greatest depths from which algae have been recorded are near Capri at 66·5 to 71 fathoms; near Minorca, 90 fathoms; near Spitzbergen, 150 fathoms; in the Barents Sea, 175 fathoms; in the Antarctic, 55·5 to 85·5 fathoms; and south of the Cape, at 40

[1] Lubimenko, Sur l'adaptation chromatique chez les algues marines, *Compte Rendus Ac. Sc.* clxxxxi, 1925, p. 730.

fathoms. Probably, however, the algae found near Spitzbergen, and in the Barents Sea, will have sunk into these depths from shallower localities.

The **Bottom** is another factor of great influence. A rocky and protected shore is a favourite haunt of algae, though many species prefer the high surf of the exposed shore. It makes a great difference whether rocks rise perpendicularly or whether they form big boulders or flats with rockpools filled with fresh sea-water at every flood and lying exposed at ebb-tide. The perpendicular rocks afford no shade to algae and only light-loving species will inhabit them, whereas broken rocks afford shelter from the sunlight and species loving shade will be found there. Rockpools are a wonderful place for collecting algae, and collectors should bear this in mind when studying sea charts in search of a fit place where they may expect algae.

A sandy bottom is poor in algae, on account of the shifting of the sand by the movement of the water, and only species with long hair-like rootlets, as for instance species of Caulerpa, can contrive to live in it. For the same reason, algae avoid places covered with fine mud, though Caulerpas may also be found there. If, however, a bit of stone or wood rises out of the mud or the sand, it will soon be covered by algae. Sea grass (Zostera marina), which is really a true flowering plant, thrives well in a sandy bottom where it can cover whole stretches and form submarine meadows. Such Zostera fields carry a rich algal vegetation, mostly of small species, attached to the Zostera leaves.

Salinity. Sea-water contains, on the average, in the open sea from 3·5 to 4 per cent. of salts; but on approaching the coast this percentage decreases in different degrees, according to the quantity of fresh water brought, by land

drainage, into the sea. Marine algae flourish luxuriantly in this medium, but if the percentage of salt falls considerably—for instance, when big streams pour their fresh water into inland seas (Black Sea, Baltic Sea, White Sea), and the water becomes brackish—true marine algae grow scarce. The transition from a rich algal vegetation to a poor one is, however, gradual, and such inland seas or big estuaries are interesting spots for investigation.

Gobi wrote two memoirs on the brown and red algae of the Finnish Gulf, where the salinity of the water gets very low. The results he obtained are interesting, for with lessening salinity Phyllophora underwent such changes that the modified forms would be taken for autonomic species if one had not seen the intervening specimens. Marine algae have an optimum, maximum, and minimum limit, with regard to salinity as well as with regard to light, and for some species those limits lie far apart.

The **Movement** of the water also influences the growth of algae. Some like places where the tidal waves rush along the coast; others prefer exposure to the high surf of the sea; and, again, others thrive well only in quiet pools. Algae are admirably adapted to profit by, or to withstand, the strong force of the waves. Some surf-loving algae have long flexible stalks that follow the movement of the water, while the blades at their top swing to and fro in the waves; other algae in the same locality can withstand the action of the waves, because their tissues are encrusted with carbonate of lime. Ocean currents are an important factor in the distribution of algae, and tidal currents often favour the vegetation of algae.

Temperature. Some algae can endure great differences of temperature without damage. Kjellman observed in Nameless Bay, Nova Zembla, Enteromorpha minima, a green alga, in fresh water of 0° C., and in sea-water of 4°

to 5° C. In the tropics the algae are exposed to the glare of the sun during ebb-tide, and in the arctic regions Kjellman found Laminariae thriving well in a temperature of 2° C., and on being exposed at ebb-tide, they even withstood a temperature of −20° C.

Algae want, however, as a rule a more congenial temperature, and if the coast of Norway has such a decidedly different vegetation from the coast of adjacent Polar lands, this is mainly due to the North Atlantic Drift, the influence of which is felt even on the west coast of Nova Zembla. Still more striking perhaps is the difference on the west and east coast of South Africa. On the latter, bathed by the Mozambique current coming from the tropics, tropical and subtropical algae flourish; while on the west coast, with its Benguela current partly coming from the Antarctic, we find a totally different vegetation. Many more examples might be cited, all showing clearly the great influence which the temperature of the sea has on vegetation. Professor Farlow describes how Cape Cod, in North America, is a boundary between two vegetations. To the north of Cape Cod, under the influence of the Labrador current, Arctic and northern European forms occur; to the south, with its Gulf Stream, species characteristic of warmer seas. Professor Setchell was able to show that a change in the kelp flora of western North America takes place with the increase of every 5° C. of surface temperature.

We touch here upon the question of the geographical distribution of algae. This is a question wanting careful investigation, for so many agencies exercise an influence on the occurrence of algae in a given locality. The Survey of Clare Island by Cotton has already been mentioned; the researches of Berthold in the Gulf of Naples, of Kjellman in the Arctic Sea, of Kolderup Rosenvinge on the coast of

Greenland, of Börgesen at the Faroe Islands, of Svedelius, Kylin, Skottsberg and many others, have opened a rich field of study with regard to the conditions of algal life and the physiognomy which algae give to the coast. When searching for algae we observe that large stretches of the coast are characterized by one or two—sometimes more—algae living, in large numbers, under the same outward conditions. Other algae may be mixed with them, but they are always in smaller numbers, or less conspicuous; they do not put a stamp on the vegetation, as the others do. Thus, for instance, Ecklonia buccinalis is a most characteristic alga of the Cape, covering large stretches of the coast in the sublittoral region. Little red algae live parasitically on its stem, but they are entirely hidden under the mass of brown blades floating on the sea. Börgesen used the term 'association' for such a community of algae, and when several associations live under the same outward conditions he called it a 'formation'. Börgesen distinguishes, for instance, a formation of encrusting algae on the coast of the Faroe Islands, and all encrusting algae belonging to it and live under the same external conditions. Börgesen calls it the Hildenbrandtia formation, after the little red alga, Hildenbrandtia, which predominates in it. Cotton distinguishes a Fucaceae formation in the British Islands consisting of: 'Pelvetia canaliculata, Fucus spiralis, Ascophyllum nodosum (moderate shelter necessary), Fucus vesiculosus, Fucus serratus, Fucus ceranoides (admixture of fresh water necessary), occurring in the order given.' Such formations and associations can vary endlessly in the different seas, according to the nature of the bottom, the salinity of the water, &c.; Svedelius has even described, for the Baltic, two detached associations of Phyllophora and Fucus at a depth of 4 to 5·5 fathoms, of which the detached specimens are

absolutely sterile and have fronds far narrower than the attached plants, growing a considerable distance away, from which the loose ones have been derived. A thorough knowledge of the formations and their components on a given coast is the corner-stone for the study of the geographical distribution of algae, so interesting in itself because it may help us to reconstruct the former aspect of the globe. By a careful study of the algae of the Baltic and Arctic Seas, Svedelius arrived at conclusions which strengthen the already existing views of zoologists, about a connexion of those seas in the Glacial Period, and in his later paper on the discontinuous geographical distribution of some tropical and subtropical marine algae, he shows that the majority of the older genera of algae have evidently had their main distribution in the Indo-Pacific Ocean, whence they have migrated into the Atlantic, in Tertiary times. A. Forti[1] has in a recent paper, illustrated with most interesting photographs, described fossil algae from Bolca (Verona) that confirm an analogy between the tertiary flora of the Mediterranean and the still existing flora of the Indo-Pacific.

Börgesen has given beautiful photographs of various formations occurring on the coast of the Faroes, and so has Cotton for Clare Island. How much might be done in this line if some of the many photographers of our day took to photographing algae! The field is still new, and might tempt a spirit keen to surmount difficulties.

It is impossible to give in a few pages a systematic survey of so large a group as the algae; their systematic arrangement can be studied in books written for that purpose. The names of the principal divisions only are given here with the most striking characteristics that are of value for the collector. Figures of very common or

[1] A. Forti, Alghe del Paleogene di Bolca, Padova, 1926.

very striking algae are inserted, and a few families are dealt with in more detail. The questions touched upon will show how interesting those families are, but other families are equally interesting from similar or different points of view. Therefore collectors of algae, who are not botanists, may feel sure that they can render good service to science if they will only collect carefully, as only well-prepared and duly labelled collections are of value.

Two little groups of algae may be mentioned first: the Parasites and the algae living in symbiosis with other organisms. True symbiosis is of profit to both partners, whereas parasites live more or less at the cost of their host. Symbiosis may take place between two algae or between algae and sponges. A beautiful instance of symbiosis is the green alga Spongocladia vaucheriaeformis; its long ramified filaments are entirely interwoven in the tissue of the sponge. The author of this chapter could follow the transformation into Spongocladia-like filaments of the leaf-like green Struvea delicatula while living with a sponge. Ceratodictyon is a red alga always found living in symbiosis with a sponge, and different species of Phormidium (Myxophyceae) inhabit different sponges.

Parasitic algae live on and in other algae. They may be so small that only the microscope will show their presence, or large and visible to the naked eye. The best-known parasite of the English coast is Polysiphonia fastigiata occurring on Ascophyllum nodosum. Its parasitic nature was first revealed by Sauvageau (1921)[1] and afterwards confirmed by L. Batten (1923).[2] But the number of known parasites is fast increasing. They occur in temperate and in tropical oceans and are often of the same

[1] Sauvageau, Observations biologiques sur le Polysiphonia fastigiata, *Recueil des trav. bot. Néerlandais*, 1921, p. 213.

[2] L. Batten, The genus Polysiphonia, *Linnean's Soc. Journ. Bot.*, vol. xlvi, 123.

family as their host. The parasitic nature of Actinococcus, Colacolepis, and Steryocolax, living on Gymnogongrus, Phyllophora, and Ahnfeldtia, is however doubtful, since R. W. Phillips suggested that investigation will probably prove that they are the tetrasporangia-bearing form of their host.

The **Myxophyceae**, or **blue-green algae**, are small, and the least organized of the algal tribe; they are either uni- or multi-cellular. The latter form long filaments enclosed in a common cell-sheath, and dividing, for the sake of reproduction, into several portions called 'hormogonia', which move out of the sheath. The young hormogonia secrete a new cell-sheath, and develop by division of their cells into a new filament. Myxophyceae, after having been collected, should, as soon as possible, be spread out on the paper on which they are to dry, and not left to stand overnight. If this is neglected, the hormogonia will, in all probability, have moved out from the sheaths and the specimen with be worthless.

Myxophyceae live, as a rule, in the upper littoral zone, attached to stones, pebbles, or other algae. Lyngbya majuscula—the mermaid's hair—is sometimes found floating on the sea. Some species of Calothrix (Fig. 46) form patches on the rocks; species of Rivularia have a hemispherical thallus, either solid, from as big as a pin's head to ½ in. in diameter, or hollow and forming soft expansions. Sometimes Scytonema and Lyngbya will cover the rocks with a slippery coating, disagreeable, and even dangerous, to the collector when the waves are strong. Myxophyceae are found in all temperate and tropical seas; their genera and species have, as a rule, a very wide distribution. In the Arctic and Antarctic they seem to be rare.

Perforating Algae. Several Myxophyceae and a few

Chlorophyceae live in the shells of molluscs, in the skeleton of corals, or in calcareous algae, where they bring about bluish, green, or violet spots. They may even attack and bore into the surface of calcareous rocks, where they bring about a blue-greenish colour. These 'perforating algae', as they are called, on account of their power to bore into calcareous tissues, are known from the

FIG 43 Chaetomorpha

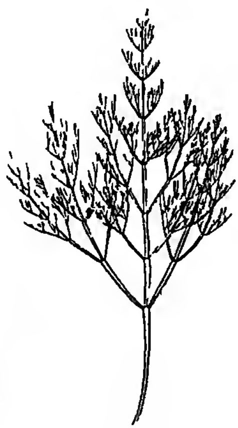


FIG 44 Cladophora

FIG 45 Ulva

temperate and tropical seas. By their incessant labour they destroy many shells, corals, and calcareous algae, setting free carbonate of lime.

The **Chlorophyceae**, or **green algae**, abound in the littoral, and are also found in the sublittoral, region. Their usual way of reproduction is by spores, which move by the aid of cilia. Some of these spores conjugate before germination, others germinate without conjugation. Of Caulerpa no reproductive organs are known. Many formations of green algae are known from the temperate and tropical seas. The filamentous Urospora, Chaeto-

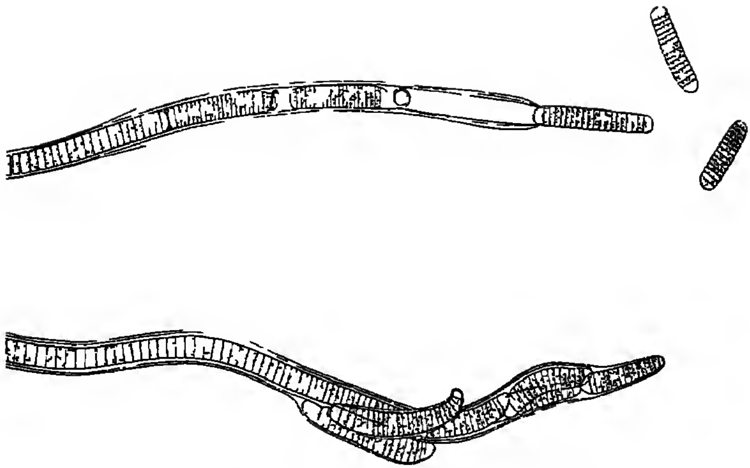


FIG 46 Calothrix The hormogonia have left the sheath or are moving out of it

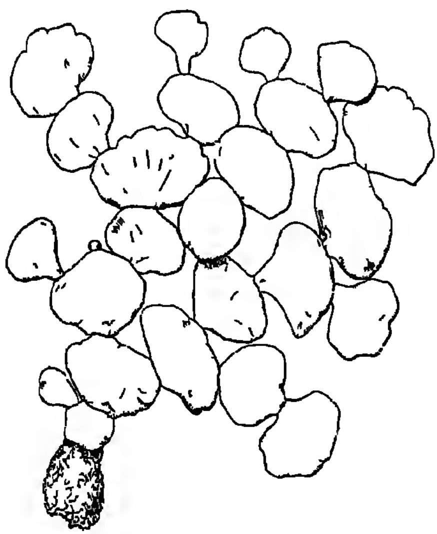


FIG 47 Halimeda macroloba

morpha (Fig. 43), Cladophora (Fig. 44), the membrane-like Monostroma and Ulva (Fig. 45), the tube-like Enteromorpha, prevail in the temperate seas, while the large group of the Siphoneae occurs chiefly in the tropics or in warmer temperate seas. The Siphoneae attain a very high

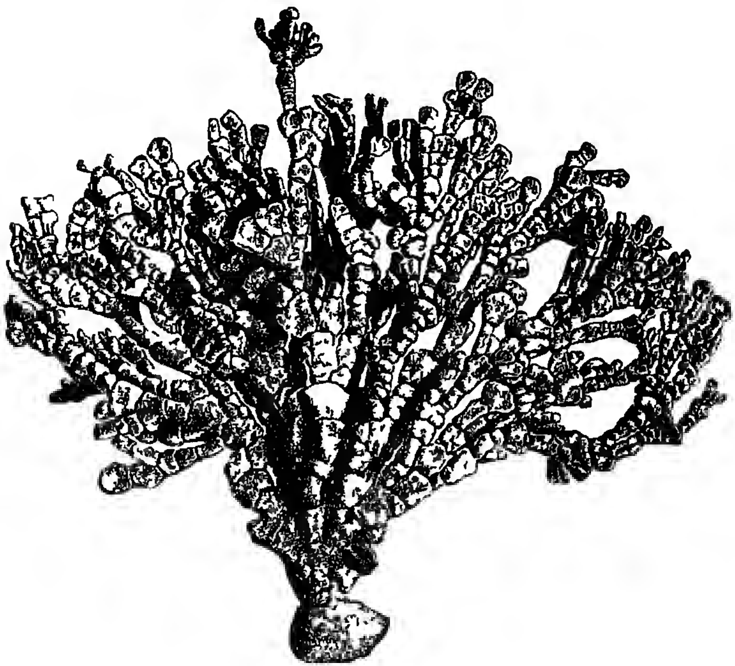


FIG. 48 Halimeda

outer differentiation, but each member of this group, however complicated the structure of its frond may be, consists of only one multinucleated cell; therefore they are called Siphoneae from their tubular nature. Many Siphoneae: Halimeda (Figs. 47, 48), Neomeris, Acetabularia (Fig. 50), Udothea (Fig. 49), Bornetella (Fig. 51), Penicillus, &c., are encrusted with carbonate of lime, and to encrustation Halimeda owes its importance as a reef-

forming organism. The Caulerpae (Figs. 52, 53) cover the coral reefs with numerous species of multifarious aspect, or live in a depth of several fathoms. Outside the tropics only a few representatives of this family are known, e.g. Caulerpa prolifera occurs plentifully in the Mediterranean; three species occur on the coast of New Zealand;

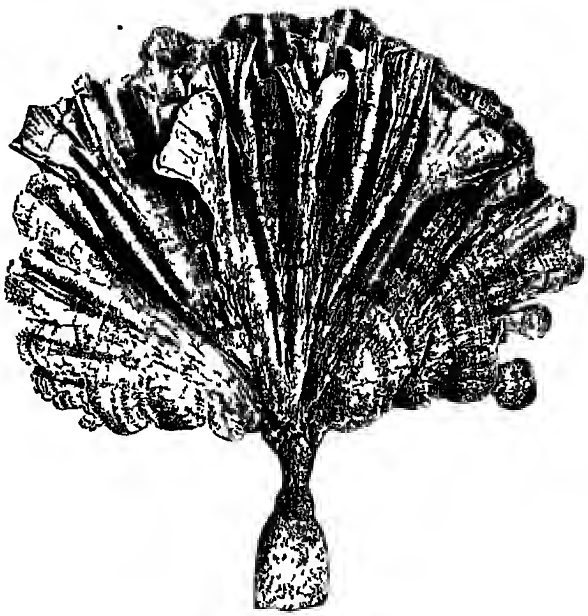


FIG. 49 Udothea

and five or six species along the coast of Japan, in the warm waters of the Kuro Shiwo, the 'Gulf Stream' of the Pacific.

Formerly the Phaeophyceae were divided into Phaeosporeae, Dictyotaceae and Fucaceae, but since the first edition of this book the systematic classification of the Phaeosporeae has undergone great changes. Sauvageau was the first to discover the alternation of generations in Laminaria. Not only many brown algae, but also many

Rhodophyceae have an alternation of generations; this consists in a generation producing only asexual motile or motionless spores (zoospores) which germinate and develop sexual female egg-cells and male antherozoids (spermatia). After fertilization of the egg-cell by an antherozoid this grows out again into a plant producing only zoospores. The alternation is, however, not always so regular, above all not in the Rhodophyceae.

The sexual and asexual plants of the brown algae are often of very different sizes. The sexual plants of the Laminariales are so small that they escaped notice till Sauvageau detected them. Other algologists discovered them in various members of the Laminariales, and Kylin cut up the old group of the Phaeosporeae into Ectocarpales, Sphacelariales, Cutleriales, Laminariales, Tilopteridales, to which afterwards Taylor added the Dictyosiphonales, and Sauvageau the Sporochnales.

In the northern seas we find numberless Ectocarpales, either as slender filaments (Ectocarpus) or forming crusts on stones and shells (Ralfsia) or bladders on other algae (Leathesia), and many more.

Sphacelariales have erect shoots springing from a basal disk and a large top cell visible by naked eye. They live mostly epiphytic, but also endophytic and parasitic on stems of Fucus and Sargassum in almost all seas.

The alternating generations of Cutleria were formerly considered as distinct genera under the names of Aglaozonia, the asexual and Cutleria, the sexual generation.

The blades of the Laminariales bear unilocular zoosporangia, and small microscopical plants born from the zoospores produce the antheridia and the egg cell that after fertilization develops into the enormous alga. The Laminariales are all alike in their youngest stages, but afterwards the blades and stripes undergo many changes

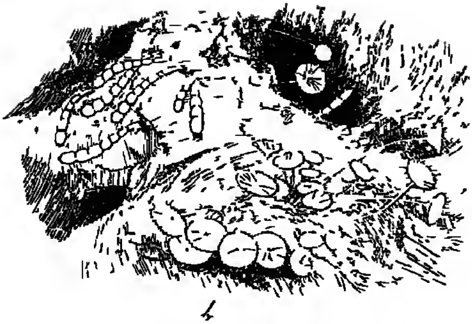


FIG 50. *a*, Cymopolia; *b*, Acetabularia

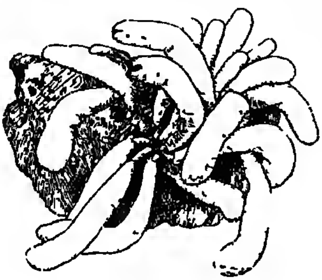


FIG. 51. Bornetella

FIG. 52. Caulerpa racemosa

FIG 53. Caulerpa prolifera

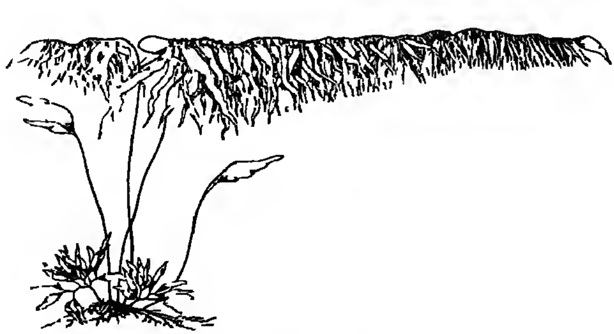


FIG. 54. Macrocystis

in the different genera that play such an important part in the physiognomy of some coasts. They live in the littoral and sublittoral zone, though it is reported that Macrocystis pyrifera (Fig. 54), with a frond attaining a length of 200 m., goes down to a great depth in the southern hemisphere. They all love exposed places, and Darwin wrote in his 'Narrative of the Beagle': 'I know few things more surprising than to see the Kelp, or *Macrocystis pyrifera*, growing and flourishing amongst those great breakers of the western ocean, which no mass of rock, let it be ever so hard, can long resist'.

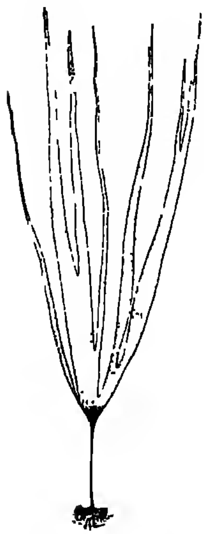


Fig. 55. Saccorhiza

The Laminariales contain much mucilaginous substance in their tissue, and the following fact, recorded by Mrs. Vallentin, from the Falkland Islands, is interesting. After describing the enormous quantities of Kelp washed ashore after a heavy gale, she continues: 'When the 'Kelp' is being torn up and the fronds and stems are being broken by the fury of the elements, the mucilaginous substance exuded from these broken seaweeds is so great, that it has almost the effect of oil in smoothing the crests of the waves. This is at times so markedly the case that the rollers lose much of their danger.'[1]

Laminariales avoid the tropics, but occur on almost all coasts in the temperate and Polar seas. The latter are rich in representatives of Laminaria, Alaria, Agarum; only three Laminariae are known from the south-west coast of Africa.

[1] Mrs. Vallentin in Cotton, On the Cryptogams of the Falkland Islands, p. 141.

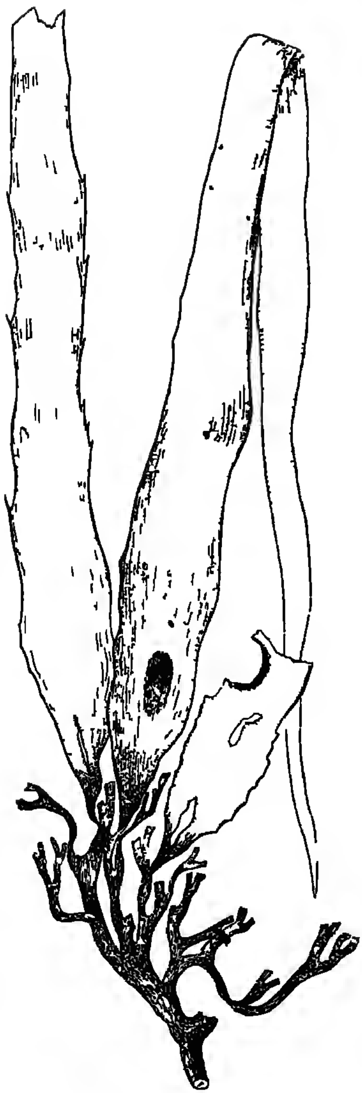


FIG. 56 Lessonia

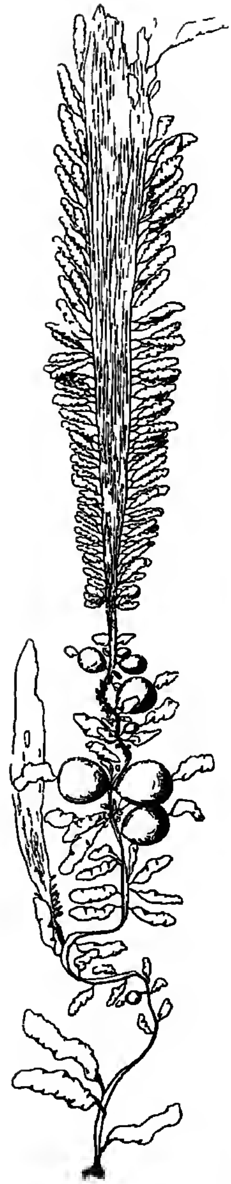


FIG 57 Egregia

Saccorhiza bulbosa (Fig. 55), common on the coast of England and Norway, is the largest European alga, with a height of 2 to 4·60 m., and a blade 2 to 4 m. in length.

Lessonia (Fig. 56) and Ecklonia (Fig. 58) are principally inhabitants of the southern hemisphere, only three Ecklonia being known from Japan. Lessonia fuscescens assumes, on the south-west coast of America, the habitus of a tree with a height of 3 to 4 m., and a trunk as large as a man's thigh. From California are known Dictyoneuron, Postelsia, Egregia (Fig. 57), Eisenia, and the gigantic Nereocystis (Fig. 59).

I should like to give some details about the Dictyosiphonales, Tilopteridales, and Sporochnales, but space is wanting. Their mode of sexual reproduction and their anatomical structure show that they are the representatives of different groups. Sauvageau urged the question that these groups, some of which have only very few actual living members, are the remnants of a rich vegetation in former geological periods.

The Dictyotales (Dictyotaceae) have light- or dark-brown ribbon-like or fan-shaped fronds, these latter often splitting up into narrow, long pieces. Their reproductive organs are motionless eggs, and motile antherozoids contained in antheridia, which form small groups, called 'sori', visible to the naked eye, and scattered over the surface of the frond. Padina pavonia has a fan-shaped frond, encrusted with carbonate of lime; it occurs on the English coast with Dictyota dichotoma (Fig. 60), Taonia and Halyseris; but Dictyotaceae otherwise prefer warmer seas, and flourish especially well in the tropics. Lobospira is exclusively an Australian genus.

Fucales or Fucaceae. The large family of the Fucaceae is characterized by their non-motile eggs and motile antherozoids being contained in special conceptacula,

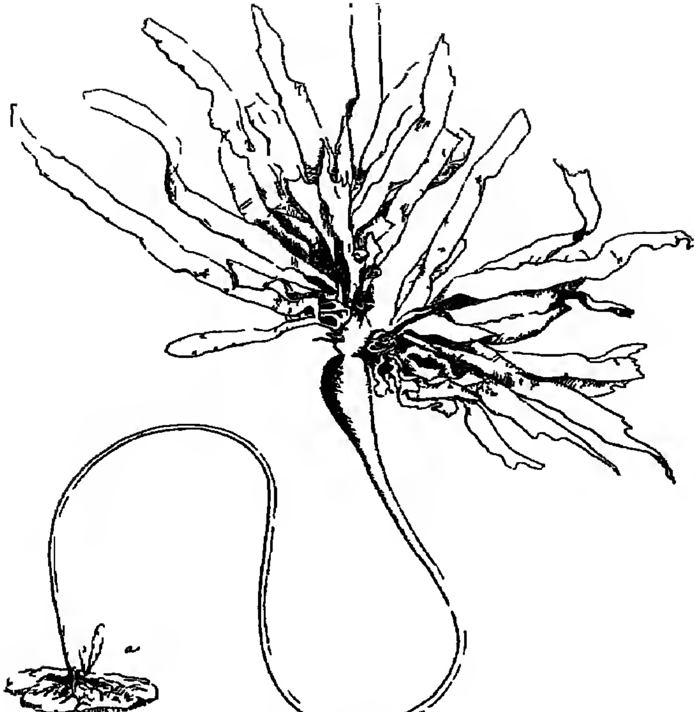


FIG 58 Ecklonia

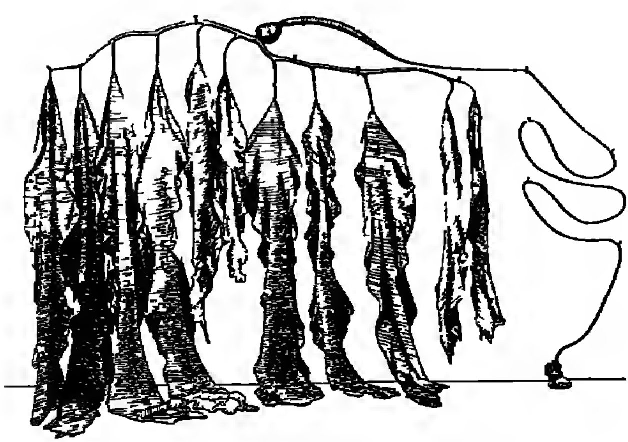


FIG 59 Nereocystis

embedded either in the frond (Fucus, Fig. 61) or in special fruit-bearing organs (Sargassum, Fig. 62). The form of their fronds is widely different; many of them have air-bladders in the continuation of the frond (Fucus vesiculosus) or special air vesicles, allowing the plant to float on the sea, when it has been torn away from its support (Sargassum). In the arctic and northern temperate regions Fucus, Pelvetia, Ascophyllum, Himanthalia (Fig. 63), and Halidrys, cover the coast with a dense vegetation. In the southern region the Laminaria-like Durvillea flourishes (Fig. 64). Australia and New Zealand are very rich in Fucaceae; we must mention from there the necklace-like Hormosira, with its parasite Notheia (Fig. 65). Scytothalia occurs in the Antarctic. Turbinaria is strictly tropical; Cystoseira, Cystophyllum, and Sargassum (Fig. 66) belong to the tropical and warm temperate seas. Of this latter genus a few words more must be said, as it has a right to claim the special attention of collectors.

In each complete Sargassum we can distinguish two parts—a short principal axis, with a tuft of rather broad basal leaves, and long branching shoots of a secondary order, with, as a rule, leaves of different size, air vesicles, and special fruiting branches. When basal and upper leaves differ from each other the transition is gradual. The fruiting branches bear conceptacula which are highly differentiated in the different species. In some species the branches with male conceptacula seem to be cylindrical, and those with female conceptacula dentate, but this question must still be carefully investigated. It is important, because J. G. Agardh divided the Sargassa into various groups, according to the form of the conceptacula-bearing branches.

The genus Sargassum has approximately 230 species, according to Grunow's latest census, and is distributed

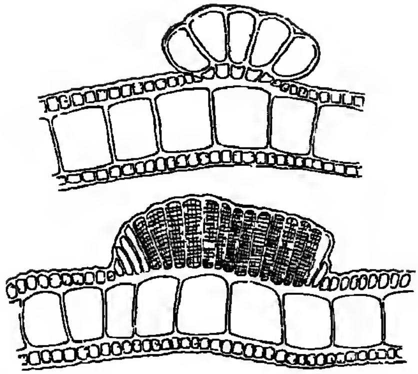


FIG. 60. Dictyota dichotoma
The sorus above with motionless eggs, below with antheridia

FIG. 61. Section through frond of Fucus

FIG. 62. Sargassum
a, Air vesicles; *b*, cylindrical conceptacula; *c*, leaf

over the warmer temperate and tropical seas; it is especially frequent on the coast of Australia. One species has for four centuries attracted the attention of men of science—Sargassum bacciferum—the alga of the famous Sargasso Sea. Discovered by Columbus, described by Humboldt, the origin of these enormous quantities of drifting seaweed is, after four centuries, still practically unknown. There are two opinions about the origin of S. bacciferum. Humboldt, Forbes, Piccone and A. Agassiz, allow the possibility of the present S. bacciferum being the floating form of one or more Sargassa that lived attached during a former period of the earth's history. If this were true, S. bacciferum must have propagated itself vegetatively for long ages, because it has been collected almost always in a barren state. Krümmel is of another opinion. In his beautiful work, 'Die Reisebeschreibung der Plankton-Expedition', he gives a very interesting chart of the distribution of S. bacciferum in the Atlantic, thereby dispelling Humboldt's error, who believed in the existence of two fixed banks of Sargassum. Krümmel assures us farther, on the authority of Kuntze, that S. bacciferum and S. vulgare are identical, and he believes that S. bacciferum is the floating form of S. vulgare, which occurs plentifully on the coast of the Bermudas. But against this opinion Sauvageau, and afterwards Börgesen, have protested most energetically; they maintain that S. bacciferum and S. vulgare are not identical. By Sauvageau's kindness, for which I hereby wish to express my sincere thanks, I am allowed to make use of letters written to him by the American algologists, Farlow and Collins, who have studied the flora of the American seas, and agree that S. bacciferum and S. vulgare are different plants. Mr. Collins, in speaking of S. vulgare, says: 'The plant in question grows attached in shallow water; I do

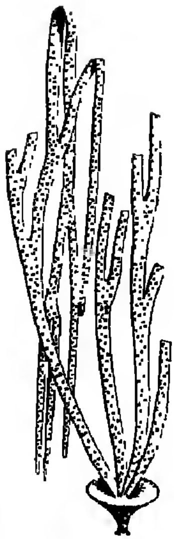


FIG. 63. Himanthalia

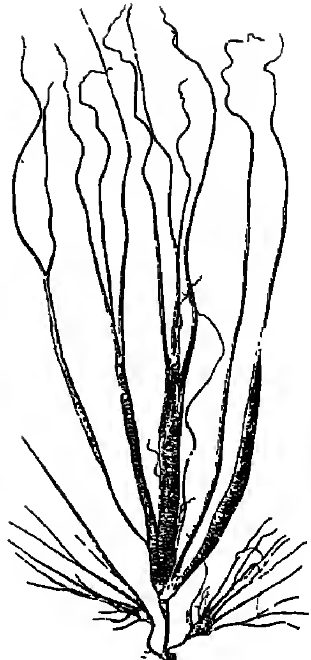


FIG. 64. Durvillaea

FIG. 65. *a*, Hormosira; *b*, Notheia

not think it occurs floating, except as any other alga that is washed ashore when torn from its fastening, but not continuing to live in a floating state.' According to Professor Farlow, it might be possible that S. bacciferum is a floating form of S. lendigerum, common in the Bermudas, but this is only a supposition; and Collins, again, says, speaking of S. lendigerum, that its shoots soon perish after having been detached.

Farlow, Collins, and Howe agree that S. bacciferum does not occur on the coast of America growing attached. The question would be solved if S. bacciferum could be forced to grow fertile specimens. This might perhaps be brought about in artificial cultures. Fertile specimens would show if S. bacciferum is only the floating form of an existing species or whether it is an autonomic species.

It is clear that intelligent collectors could do much to advance our knowledge of the Sargassa. They should try, above all, to bring home entire plants, with rootlets and basal leaves as well as with the long secondary shoots, and not forget that fruit-bearing branches are of great interest.

Rhodophyceae. In genera and species, though not in bulk, the greater part of marine algae are Rhodophyceae; they are usually small in size, with the exception of some species of Halymenia, Gigartina, Iridaea, &c. They are, as a rule, soft and slippery to the touch, and of a bright red colour, except in places exposed to the glare of the sun.

The beauty of red algae is something exquisite, and every collector will consider his trouble well rewarded if he has been fortunate enough to collect some of these lovely algae.

The organs of fructification of this great group are essentially alike, and consist of asexual cruciate or tripartite motionless or slowly sliding spores, antherozoids, and a carpogonium with a basal part containing the egg-

cell, and a hair-like top, called the 'trichogyne'. The small antherozoids adhere to the trichogyne, pierce its cell-wall and their contents, and entering the trichogyne, fertilize the

FIG. 66. Sargassum

egg-cell. After this fertilization, a complicated process takes place, the result of which is the cystocarpic fruit, consisting of a globular mass of spores, either borne free (Nemalion), buried in the tissue of the frond (Halymenia), or contained

within special conceptacles. These latter are the typical cystocarpic fruits proper to the group of the Rhodomelaceae. Polysiphonia urceolata (Fig. 67), common on the English coast, is a good example to show the cystocarpic fruit.

To the Rhodophyceae we may also reckon at least partially the Bangiales, formerly called Proto-Florideae, since the beautiful investigations of R. W. Phillips on Gracilaria.[1] In Gracilaria and in the genus Porphyra (Bangiales) the trichogyne is reduced to a simple papilla on a peripheral cell, which in this case is the Carpogonium. In Porphyra the carpogonium after fertilization may become a spore or divide into several spores; in Gracilaria fertilization 'is followed by the formation of the cystocarpical swelling and the egg-cell embedded at the base of the proliferated tissue, gives rise ultimately to the carpospores'.

The Rhodophyceae, or Florideae, are found in all seas, but they prefer the temperate and tropical regions. Many of their genera have a limited, others a wide, distribution, but it does not follow that the species of these latter have also a wide distribution. It may be so, but more often they are limited to smaller localities.

The Rhodophyceae are divided into Bangiales (pr. p.), Nemalionales, Cryptonemiales, Ceramiales, Gigartinales, Rhodymeniales. Among the Bangiales, Porphyra is the most common and well-known alga of English shores.

To the Cryptonemiales belongs an important group amongst the red algae, the Corallinaceae, so called on account of the carbonate of lime which they secrete and deposit in their cell membranes, with the exception of the cells of the reproductive organs and those in the joints of the Corallineae. By this process they grow as hard as stone, and have for this very reason contributed largely to the

[1] R. W. Phillips, Cystocarps of Gracilaria, *Ann. of Bot.* 1925, p. 39

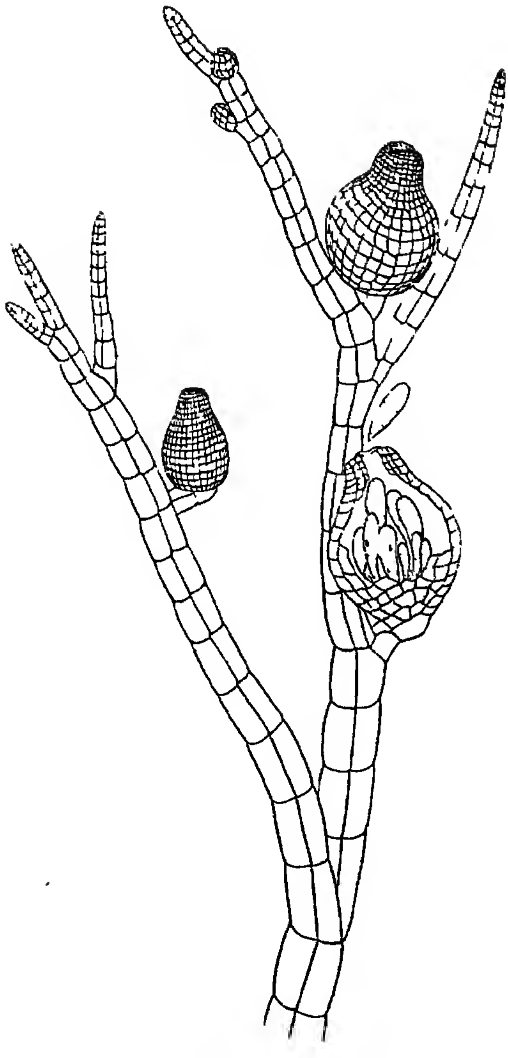


FIG. 67. Polysiphonia

formation of the earth's crust. They are known from very early periods in the earth's history, for Lithothamnium jurassicum is already reported from Jurassic strata; in Cretaceous deposits they appear plentifully, and in Tertiary times they were so numerous that entire mountains were built up by them. The well-known Latomien, near Girgenti, in Sicily, are quarries in rocks consisting of Lithothamnia. In our present day they continue their work, and occur in enormous quantities, forming banks in the polar, temperate, and also in the tropical seas, where they contribute largely to the building up of coral reefs. The late Mr. Foslie, the well-known authority on Lithothamnioneae, kindly told me, in a letter which he allowed me to quote, that the number of known species was 276. Of these, approximately 12 are strictly arctic or sub-arctic; 82 are limited to the tropics; and 182 occur in the temperate zones. Since his death the work on the Melobesieae has been pursued by Mme Lemoine, who besides giving us a good classification, has described many new genera and species. The Corallinaceae are divided into Corallineae and Melobesieae. From Corallineae are best known the slender and bush-like Corallina, Amphiroa, and Arthrocardia. To the Melobesieae belong Melobesia and the encrusting or free-branching Lithophyllum (Fig. 68) and Lithothamnium (Fig. 69). The encrusting forms often act like mortar to cement loose material together; the free-branching forms develop into nodules even bigger than a man's fist, and, cemented together, they can form masses of more than a mètre in diameter. All Corallinaceae are fond of strong currents; Corallina and allied genera love places exposed to the surf of the sea; Lithophyllum and Lithothamnium prefer the sublittoral zone, and go down to depths even of 30 to 40 fathoms. The author has seen a bank of Lithothamnium dry at spring-tide, near the

island of Timor, but this is an exceptional case. It is a curious fact that, however large a Lithothamnium bank may be, it consists chiefly of only one species. Such banks figure frequently on sea-charts as 'corals'. For the Litho-

FIG 68 Lithophyllum

FIG 69 Archaeolithothamnium

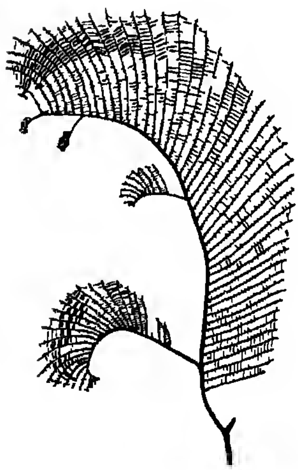


FIG. 70 Claudea

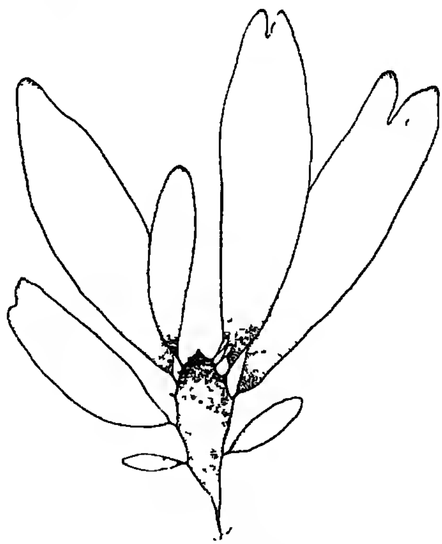


FIG. 71. Rhodymeni

thamnioneae the rule holds good as for other algae, from warm to boreal or arctic seas the number of species decreases, but the number of individuals increases.

The red algae are so numerous that it is difficult to choose which deserve special mention. To the Ceramiales

belong Ptilota, common in northern seas; Ceramium, Polysiphonia (Fig. 67), Laurencia, plentiful both in temperate and tropical seas; the latter being the favourite haunt of Claudea (Fig. 70) and Martensia. Delesseriaceae are found in all seas, but seem to prefer colder water; Skottsberg and Kylin have described many new genera and species from the Antarctic. The genus Eucheuma, belonging to the Gigartinales, abounds in the tropics, and Rhodymenia palmata (Fig. 71) is common on Irish and Scotch shores. I fear that I have perhaps already mentioned too many. The reader may be reminded of Harvey's Quaker, who said: 'Brother, if thou knewest what I keep in, thou wouldst not grumble at what I let out.'

In 1899 there appeared from the hand of Professor W. A. Setchell a paper containing directions for collecting and preserving marine algae ('Erythea', vol. vii, No. 3). Whatever the learned Professor advises the collector to do, as to the best methods of collecting and preserving algae, is the best that can be done. I can only add a few details, and it is therefore with the kind permission of Professor Setchell that I transcribe here some passages out of his paper. For full information on the subject I refer the reader to that paper.

Collecting and Preserving Methods. Wherever a collector goes to seek for algae, he must first find out the time of the tides from the local authorities. The collecting ground should be reached from one to three hours before the occurrence of extreme low water, in order that the collector may follow the tide as it goes down. In this way the littoral region can be explored; the upper part of the sublittoral can only be reached by wading; its lower part lies too deep for wading, and recourse must be had to a boat. From the boat many species may be seized, and

hauled into it by means of an ordinary garden rake, if the water be quiet enough; otherwise it will be necessary to use the dredge, and that must always be used as a matter of course where the water gets deeper. If the bottom is rough, care should be taken to protect the bag of the dredge on both sides with strong sailor's canvas. If this is not done the meshes of the net will be easily caught by corals or stones; protected by canvas, the net will often glide over these impediments. The success attending the use of the dredge will depend upon local circumstances. Farlow, in his 'Marine Algae of New England', called a day spent in dredging a wasted day; but during the Dutch Siboga Expedition the dredge has several times brought up a rich harvest, and, used by the Belgian Arctic Expedition, the results were often 'a fine vegetation'.

The author once had in the tropics, at a depth of 6 to 7 fathoms, the help of divers, and it proved a great success. Berthold attained much by diving himself. The new diving apparatus makes diving more attractive than it formerly was and may in time become a great help in collecting specimens not attainable by hand.

Collectors should not forget to search the coast carefully after a stormy day, for at the time of maturity the algae of deeper water are more or less readily torn away from their attachments; they rise to the surface, or near to it, and are drifted ashore, especially after storms.

To the collecting apparatus belongs, first of all, a general receptacle for the transport of the collected material. A good canvas or rubber bag, with a flap for closing the mouth, and a broad strap for the shoulder; a basket, a canvas pail, or a large net with straps, are all very useful implements, out of which one may be chosen according to the collector's tastes. It is also very desirable to have some bottles with preserving fluids. To carry

these we used a zinc box (Fig. 72), 35 cm. long, 25 cm. high, and 11 cm. broad; it was a little concave on the side turned towards the body of the bearer. Inside it contained, at some distance from the bottom, a stand for loose bottles of various sizes.

Specimens for drying may be wrapped at once in newspaper, a large quantity of which should form part of a collector's outfit.

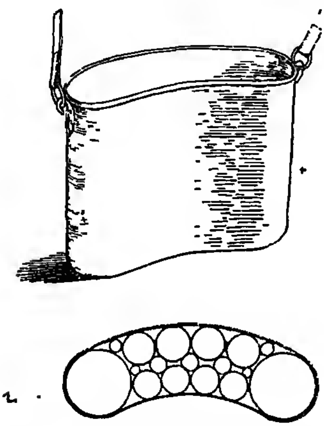


FIG. 72. Zinc Box for carrying bottles *a*, Plan of stand for loose bottles

A knife, well anointed with vaseline to prevent rusting, and a fairly powerful pocket lens, are absolutely essential. A spoon or a pair of small forceps are of service in gathering from rocks small gregarious algae, and a small geological hammer and chisel are necessary if occasion arises to collect encrusting species growing on rocks. A pair of fisherman's boots with extensible legs reaching to the hips are necessary for wading in temperate seas; ladies will do well to dress in a rather heavy skirt of pure wool and high boots; in the tropics a bathing-costume of thin woollen material will be the thing for ladies, but care should be taken to protect the feet against the spines of sea-urchins or the rough surface of coral reefs. In some localities it will be safer for the collector to go out with a rope tied round the waist and firmly held by friends in a safe position on shore, on account of treacherous holes in the rocks and reefs; in others the waves may, at the turn of the tide, run in so suddenly and violently that danger of getting drowned is imminent if

proper care is not taken. Collectors should study carefully each special locality—above all, on exposed rocky shores—before risking themselves too far out at ebb tide.

On the collecting-ground the best specimens available should always be selected, and, if the fruit can be detected, fertile specimens should be carried home in preference to sterile ones. Specimens covered with parasites should only be gathered for the sake of the latter. When botanizing on algologically poor and rarely visited coasts or reefs, it is best to take whatever can be found, in order that we may get an insight into the nature of the flora; but, as a rule, only specimens in a good state of preservation should be taken.

The methods of preserving algae depend on whether they are required for research in the laboratory or for the herbarium. For laboratory work they must be put in various fluids, best studied in papers enumerated at the end of this book. For each special investigation there are almost always special methods of preservation. For general investigation, algae may be put at once in alcohol of 70 per cent., or in a solution of formalin (1 to 2 c.c. formalin in 99 to 98 c.c. fresh water).[1] In alcohol algae will shrink a little and lose their colour; in formalin they do not shrink, and keep their colour a long time if kept in the dark. But, in the long run, a solution of formalin affects the tissues slightly. One per cent. chrome alum in distilled water, carefully filtered through sand, is, according to Guignard and Lotsy, an aqueous solution that does very well for Myxophyceae, Chlorophyceae, and Rhodophyceae; Phaeophyceae do better in formalin.

For the herbarium algae can be either roughly dried, or mounted and pressed, or salted, as desired. Large algae,

[1] Sea-water can also be used for making up solutions, but rusts all steel instruments used on the material afterwards in a most annoying way.

such as Kelps or species of Fucus, can be very well dried in the air, care being taken to shut out the glare of the sun, in which the algae dry too soon and become brittle. The method of drying successfully in the air will depend upon the moistness or dryness of each climate. In Norway Kelps dried beautifully on being exposed to the wind. To save space, one may fold or roll up big algae, care being taken to do this before they are too dry and too brittle. They should afterwards be allowed to dry further. It is absolutely necessary to let Kelps dry before folding them up, or before putting the small ones into the press; for if put into the press at once they easily become mouldy. The dried specimens can afterwards be moistened again; the water absorbed in soaking them out will be very easily given up in the press.

The plants to be pressed for the herbarium ought to be carefully washed and sorted in sea-water, in which they retain their colours better than in fresh water. In a few cases it may be advisable to wash the algae in fresh water before putting them into press. Travellers will prefer photographic dishes for this sorting and the subsequent spreading, but collectors living near the sea-side will find common earthenware dishes, white on the inside, preferable. For floating out the specimens, a method of the late Mr. Holden is to be recommended, which I quote from Professor Setchell's paper.

The utensils are very simple—a shallow dish and a rectangular piece of zinc, just a little smaller than the bottom of the dish. The corners of the zinc (or two sides) are bent over at a sharp angle, all the same way. The piece of zinc is then placed in the dish, with the bent portions downwards, so as to raise the main portion of the zinc somewhat from the bottom of the dish. Water is then poured in—fresh or salt, as the case may be—until it is

just the least bit above the surface of the piece of zinc. Now take a piece of white paper or card, lay it with one surface on the zinc, and turn it over, thoroughly wetting both sides. Then place the specimen to be mounted, carefully cleansed, upon the paper; with the forefinger of the left hand gently depress the paper and zinc, until the specimen is floating freely. With the right hand spread out the specimen upon the paper, using a pair of needles or a soft brush to assist in the process. When finally spread out gradually release the pressure upon the zinc, allowing it to rise and to drain off some of the water. Then gently lift the zinc until the whole of the specimen is out of the water. When the paper is fairly dry, but before the alga has begun to show the effects, the specimen is placed upon a sheet of drying-paper, a thin cloth is put over it, another drier upon that, a specimen upon that, and so on. A flat board with some stones makes a very good press; better still is a press consisting of two iron frames, with a network or iron wire in the middle (Fig. 73), and each frame provided with four little hooks. These little hooks are fastened together by four copper chains that can be made shorter or longer, as circumstances require. The chains must be fastened loosely, and only a little weight placed on the board in the beginning. The specimens may be pressed more strongly the second day. It is absolutely necessary to change the driers every day, and it is better still to change them twice a day in the beginning.

For mounting the algae, white, unglazed, tough paper is the best; the driers must be of pretty thick drying paper, or sheets of blotting paper. The cloth must be a thin cloth or muslin, entirely free from starch. Most of the finer specimens will adhere sufficiently to paper, but the coarser ones must be afterwards fastened on to the mount with

narrow strips of gummed paper. We have already said that blue algae must be spread out at once after having been collected. It is best to let them dry in the air. Each specimen should be provided with a label, on which must be mentioned the locality where it was collected, the date, the nature of the bottom, the depth, and a number, beginning with 1, and so on. The numbers of the specimens must also be entered in a notebook wherein all details are to be mentioned that strike the collector, such as the different shades of colour which some algae have in and out of the water, and the periods of the year in which they occur; for many algae have regular periods of growth and rest just like the higher flowering plants.

Utility of Algae. The commercial value of algae is relatively small. Formerly large quantities of Kelp and Fuci were gathered, and even grown, on the coasts of islands near Ireland and Scotland, for the manufacturing of carbonate of soda. This was, however, afterwards given up. Kelps are still collected for the manufacture of iodine. Many algae, especially the Kelps and the Fuci, are gathered as manure, and on the coasts of Ireland and France large quantities of calcareous algae known as 'Maerl' are collected for the same purpose.

Cows are fed in winter-time in northern Norway on Rhodymenia palmata (Dulce) if other fodder is scarce, and during the Great War experiments were made in France to feed horses on duly washed out Laminaria flexicaulis and L. saccharina. The horses that conquered their dislike of this food throve very well and added to their weight, though doing their ordinary hard work. Unfortunately the number of horses that would take to this diet was small. In Iceland horses are fed on Kelp in winter-time.

In the Malay Archipelago and in Japan various species of algae are consumed by the people, and species of

Eucheuma, Sphaerococcus, and Gelidium are gathered in enormous quantities for the manufacturing of the famous Agar-Agar, known in Japan as 'Kanten', which word signifies 'cold weather' and implies that Kanten can never be prepared in a hot climate, but only when the temperature is rather low. The Japanese eat also a dish 'Amanori' made of Porphyra; 'Kombu', made of various Laminaria,

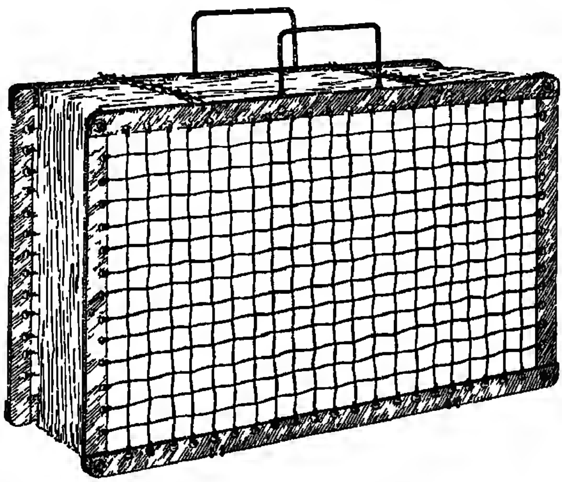


FIG 73 Press for drying Algae

is an ordinary food of the people. The commercial value of algae is rather high in Japan.

On the west coast of America acetone, for the fabrication of cordite and black powder, was extracted during the Great War from the Giant-Kelp growing along the coast. But it is doubtful whether this manufacture will be kept up now the demand for cordite has lessened. For manure great quantities of Kelp are gathered.

The real importance of algae in oceanography lies in the fact that they form the basis of the ultimate food supply of the neritic or coastal fauna.

V

THE FLOATING ANIMALS

BY G. H. FOWLER AND E. T. BROWNE

To those animals and plants which float or drift in the water, either shallow or deep, 'dead or living', the term Plankton was originally applied by Hensen. Later on Haeckel applied it so as to include all pelagic animal and plant life as a whole, in contrast to bottom life, either fixed or crawling, as a whole, which he termed Benthos. Haeckel's definition is now sometimes adopted, and it takes in all the powerful swimmers, such as fish, but in this chapter only the floating and drifting animals are dealt with. Plankton is also subdivided according to the size of the organisms into two groups; the microplankton consisting of very minute organisms which require the use of a microscope for their determination, and the macroplankton for the larger organisms, but the division is rather an arbitrary one.

None but zoologists appreciate the wealth of animal life in what appears to be clear, barren sea-water, and this is only revealed when a suitable fine meshed net has been hauled for a few minutes through the water, or when one realizes that the Greenland whale, 50 ft. long, lives solely on the smaller plankton.

Most groups of the invertebrate or backboneless animals are represented in plankton, and the main types, which are likely to be captured near the surface, will now be briefly sketched.

The figures, which in most cases have been a good deal simplified from the originals, and the text give only sufficient detail to help the beginner in finding out the group to which a specimen belongs. The exact position in the

Animal Kingdom of each form named will be found in the classification (p. 475). In order to find the real names of the animals, or to learn something of their structure and life-history, the reader must consult the ordinary text-books, monographs, and special memoirs cited.

Animals are divided into two great sub-kingdoms, according as they are composed of a single cell (Protozoa), or of many cells (Metazoa).

Of the single-celled animals, several groups occur in the plankton, and are distinguished for their great beauty and interest. The pelagic Foraminifera form a shell of lime and are abundant in tropical and subtropical regions, where their dead shells form a deposit on the floor of the oceans known as the Globigerina ooze (see p. 261). They also occur in the temperate regions, but decrease in number as the water becomes colder. The shell, into which the animal can be completely withdrawn, consists of successive chambers, generally more or less spirally arranged, opening by a mouth from the largest chamber, and also perforated all over by fine holes. From the chambers radiate extraordinarily delicate spines of lime, which not only help to prevent the animals from sinking by increasing the frictional resistance to the water, but also allow the living matter (protoplasm) flowing out of the shell-mouth and fine holes to form a sort of bubbly lather between them, and to put out long threads for the capture of prey. The commonest genus is Globigerina (Fig. 74).

Another group is the Radiolaria, which usually have shells or skeletons of glass-like silica (Figs. 75, 76, 77, 78), which make most beautiful microscopic objects, or of a horny substance called acanthin, which is a complex silicate (Fig. 79), or of some other mineral (Strontium), but never, like the Foraminifera, of lime. These hard frames,

which are covered by cytoplasm, have developed in a complexity of forms and variety of detail that are found

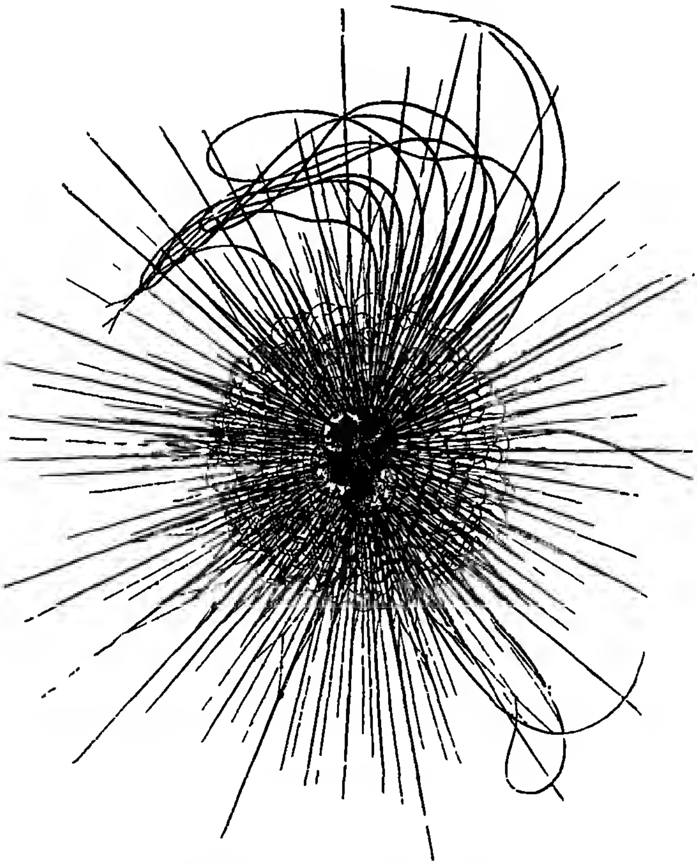


FIG 74 Globigerina (from a Living Specimen) (*Challenger*)
The central dark mass is the shell (compare Fig. 156, p. 261), from which radiate stiff spines of lime. Round the shell is a bubbly mass of living matter, from which fine granular threads extend between the spines, generally straight, but some curved.

in no other group of animals. Some have the skeleton in the form of two valves (Fig. 80), free or hinged together, and others have a kind of projecting fringe to the shell

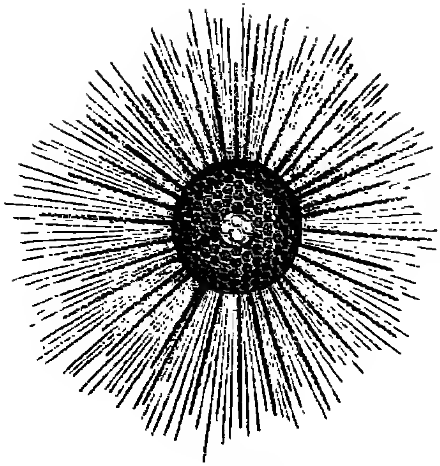


FIG. 75. Heliosphaera

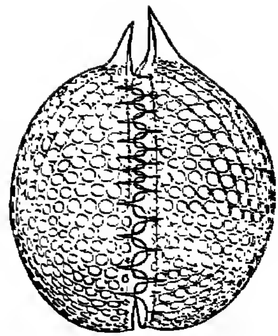


FIG. 76. Conchidium

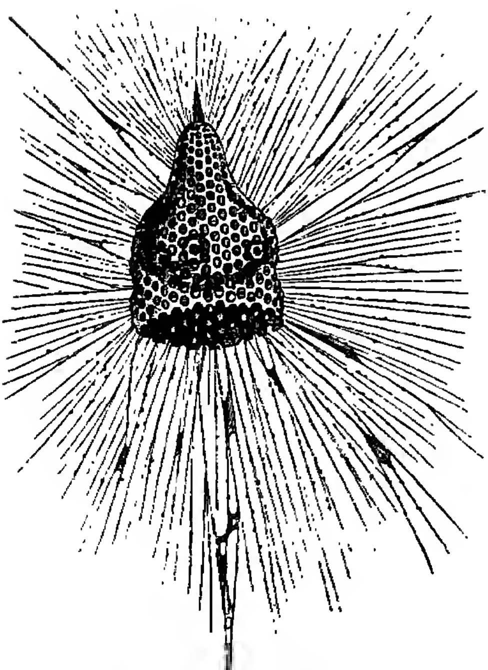


FIG. 78. Eucyrtidium

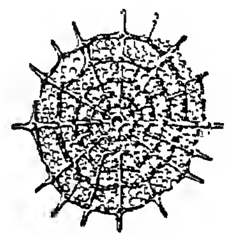


FIG. 77. Stylospira

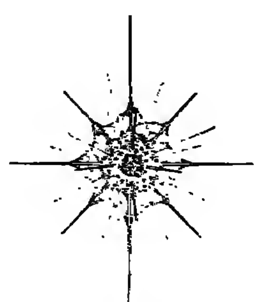


FIG. 79. Acanthometra

(Fig. 82). A few, however, are without a skeleton, but may have spicules, others form small colonies (Collozoum), having the individuals embedded in a mass of jelly.

Radiolaria occur in vast quantities in the tropical and warm regions, to a lesser extent in the temperate zones, but some prefer cold water (Fig. 84), and others only live at great depths (Fig. 81). Like the Foraminifera, their skeletons form an ooze at the bottom of the deep oceans. In most Radiolaria peculiar nucleated yellow corpuscles are found in abundance, and they are regarded as symbiotic algae.

The Ciliata have no skeleton or shell and swim by means of cilia. Many genera occur in the sea, but they require special searching for, and are seldom abundant.

The Flagellata move about by the movement of one or more flagella, and some form colonies. In the group some naturalists place Ceratium (p. 156, Fig. 35) and Peridinium (p. 157, Fig. 36), whilst others consider them to be members of the Vegetable Kingdom. There is, however, one conspicuous flagellate, Noctiluca (Fig. 83), which is enormous in size for this group. It is also brilliantly phosphorescent, and when occurring in vast shoals lights up the surface of the sea at night upon its being disturbed.

In the course of evolution the Protozoa gave rise to the Metazoa, the many-celled animals, and these at the outset divided into two branches. One produced the Porifera or Sponges, and then remained stationary; the other gave rise to the Coelentera, and through them all the other groups of the Animal Kingdom. The Coelentera include the sea anemones, corals, and various groups of animals usually called 'jelly-fish', which are among the commonest and the most beautiful organisms in the plankton.

Any one not familiar with the classification of marine

animals would call any animal a 'jelly-fish' which has the consistency and appearance of a jelly. But it is necessary to limit the name, even in its popular sense, so as to

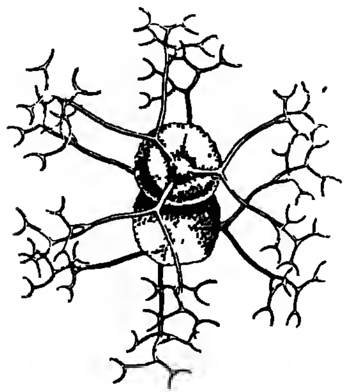


Fig 80 Coelodendrum

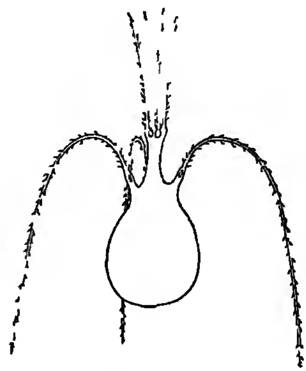


Fig 81 Tuscarora

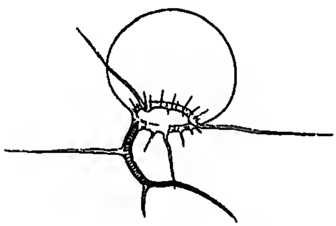


Fig 82 Euphysetta

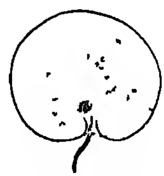


Fig. 83. Noctiluca

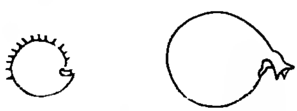


Fig 84 Two Species of Challengeron

exclude the swimming Salps (p. 228), which are most likely to be mistaken by the uninitiated for true jelly-fish. The former are quite different in shape and structure, and are nearly related to the Vertebrates (cf. Figs. 149 and 150 with Figs. 85 and 90).

The jelly-fishes may be separated for the sake of

convenience into four groups—(1) Hydromedusae, (2) Scyphomedusae, (3) Siphonophores, (4) Ctenophores—each of which has well-marked characters. The jelly-fishes belonging to the first two groups are commonly called simply Medusae.

The Hydromedusae are small in size, seldom exceeding an inch in diameter, and are caught by means of a tow-net. They may be subdivided into two groups: (1) neritic or shore forms; (2) oceanic or blue-water forms. The neritic forms occasionally drift out into the ocean, but, as a rule, they become scarce beyond the 100-fathom line.

The neritic Medusae (Figs. 85, 86) are budded off from small animals called 'zoophytes', or 'hydroids' (Figs. 87–9), which form colonies, and are permanently fixed at the bottom of the sea, or in some cases to floating objects. The hydroids, which thus bud off Medusae, do not develop eggs, and are, therefore, asexual. The little Medusae, after leaving their hydroids, begin an independent free-swimming career. In the course of growth and development they usually pass through a series of progressive stages, and finally become sexually adult. The eggs from the female Medusa do not develop into Medusae, but into hydroids, so that there is an alternation of generations.

The geographical distribution of these littoral Medusae depends upon the habitat and distribution of their hydroids. Some have a very wide range; others are limited to definite localities. It is the bathymetrical limit of these hydroids, which seldom extend to a greater depth than the 100-fathom line, that confines this group of Medusae to the littoral waters.

The oceanic Hydromedusae have not a fixed hydroid stage, and the eggs develop directly into Medusae. Their natural habitat is the ocean, but occasionally they drift

into littoral waters. The species generally have a very wide geographical range, and some are found at great depths.

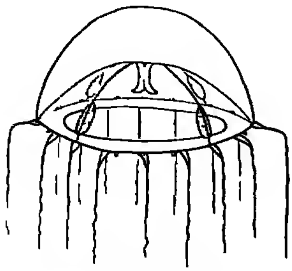


FIG. 85 Phialidium

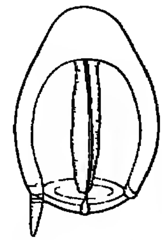


FIG 86 Euphysa

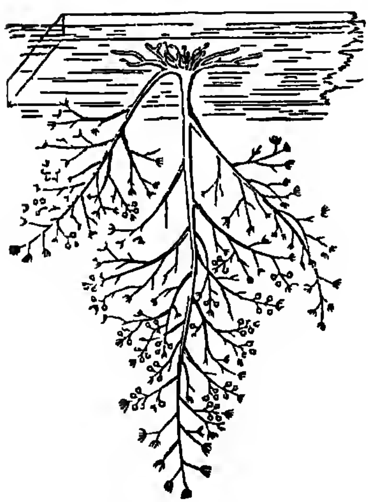


FIG 87 Colony of Bougainvillea attached to a Floating Bit of Wood

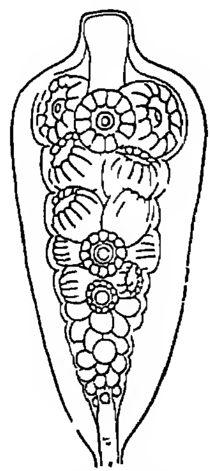


FIG 88 Obelia Showing jelly-fish being budded at the sides of a special polyp

The large jelly-fishes, which are commonly seen from the deck of a ship slowly swimming at the surface of the sea, or found stranded on the shore by the receding tide, are representatives of the Scyphomedusae (Figs. 90, 91).

A few have the power of stinging like a nettle, but most of them may be handled with impunity. One (Fig. 91) is noted for its brilliant phosphorescence, and at night has the appearance of a globe of fire gliding through the water.

Some of the Scyphomedusae have an alternation of generations. The eggs from an adult Medusa develop into tiny anemone-like animals, which are attached to stones, shells, &c., at the bottom of the sea. These fixed forms finally give off a number of little free-swimming rayed disks, called Ephyrae, which develop into adult Medusae. Others omit the fixed stage in the course of development, and the eggs develop directly into Ephyrae (Fig. 92).

The Scyphomedusae are found all over the world; some are oceanic, and others are more at home near the shore. A few live deep down in the very cold zones of the oceans.

The Siphonophores (Figs. 93–6) are closely related to the Hydromedusae, but most of them have not the appearance of a jelly-fish. Although some are fairly simple in their construction, others are extremely complicated. They usually have the appearance of a colony of animals composed of different kinds of individuals.

This group contains some of the most beautiful, the most delicate, and the most fascinating animals that live in the sea. They are typically oceanic animals, and keep afloat by the aid of air-sacs or oil-globules. Nearly all swim, often at a good pace, by means of special organs called 'swimming bells'. As a rule, they keep below the surface of the sea, and a few have been taken at a very great depth. They are found all over the world, even under the ice off the Antarctic continent, and the species have usually a very wide geographical range.

FIG. 89. Part of colony of the Hydroid Bougainvillea
Showing the polyps with long tentacles, and the round or bell-shaped Medusae (jelly-fish) which are budded off from the colony when adult

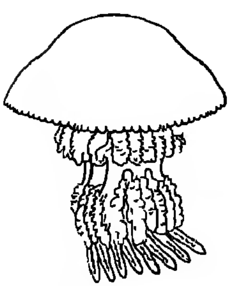


FIG. 90. Rhizostoma

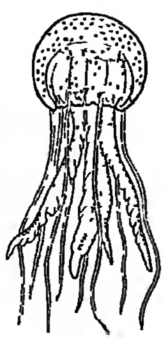


FIG. 91. Pelagia

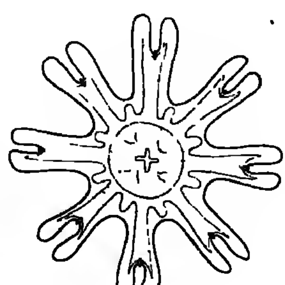


FIG. 92. Ephyra, or Young Aurelia

Their life-history is very complicated, and in the course of development they pass through stages which are not at all like each other, either in structure or general appearance.

To the Siphonophores belongs the well-known Portuguese man-of-war (Physalia, Fig. 94). This is the largest Siphonophore, and it floats by the aid of an air-sac at the surface of the sea. Its stinging power is tremendous, producing a maddening pain which lasts for hours. Another

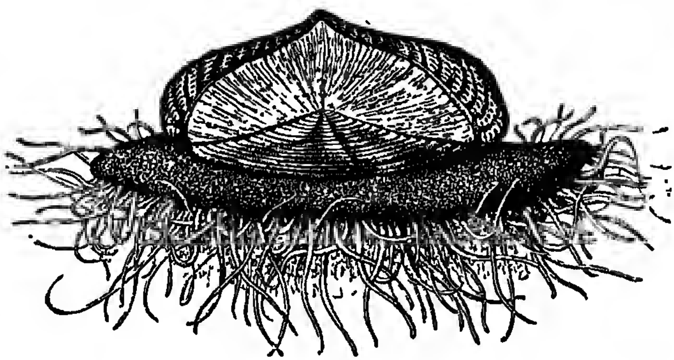


FIG 93. Velella

common form is the little blue Velella (Fig. 93), which also floats at the surface, and is not infrequently blown ashore.

Adult sea-anemones (Actiniaria) are rarely found in plankton; but larvae of anemones, which eventually affix themselves to or burrow in the bottom, are fairly common near shore, and one, at least, is found on the high seas north and west of Britain (Arachnactis, Fig. 97).

The group known as Ctenophora, from their comb-like paddles, is common; Pleurobrachia (Fig. 99) may be taken off our own coasts; with its two graceful tentacles, it plays its prey exactly as an angler plays a salmon. Cestus, or Venus's girdle (Fig. 98), is an inhabitant of

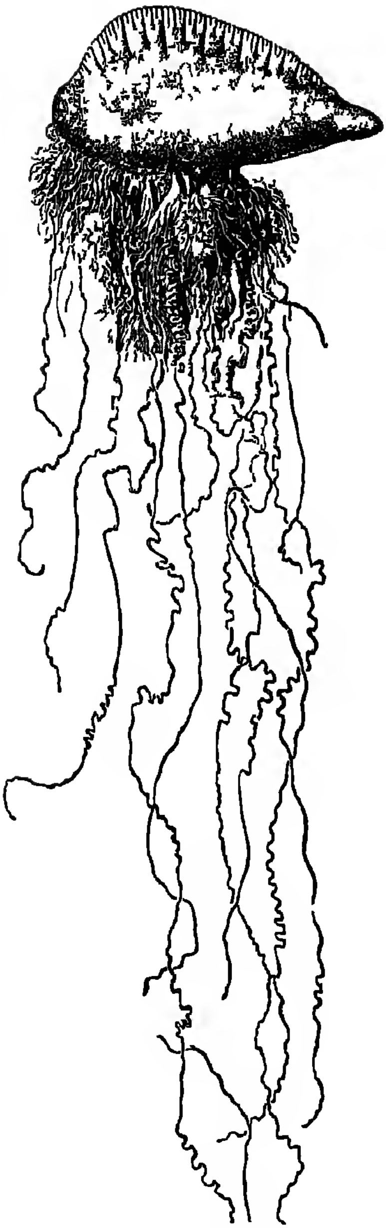


Fig 94 Physalia

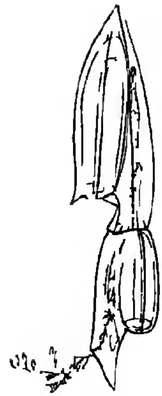


Fig 95 Diphyes

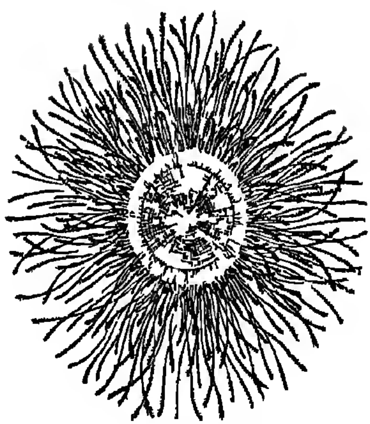


Fig 96 Porpita

Fig 97 Arachnactis

warmer seas. Beroe (Fig. 101), a glove-finger of pink jelly, also occurs off our coasts.

The various groups of flatworms are rarely met with in plankton, and consequently should be carefully preserved if found. But the group of roundworms (Chaetopoda), to which belong the common earthworm, and the ragworm and lugworm beloved of sea-anglers, require mention. Near shore swimming larvae, which ultimately grow into

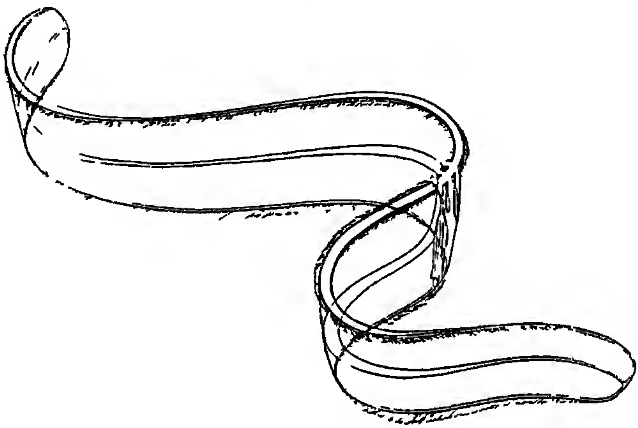


FIG. 98. Cestus or Venus's Girdle

crawling or burrowing adult worms, are frequent at some seasons; Fig. 102 shows some of the simpler forms. Many are provided with long bristles, such as give the name to this group ('bristle-feet'). Of adult forms, perhaps the commonest is Tomopteris (Fig. 100), sometimes 2 in. long. Of the Nereids or ragworms, some are occasionally captured near shore, apparently at the breeding season. Of the curious Syllid worms (Autolytus), some reproduce asexually by forming a second or even several heads in the course of the body, and then dividing into as many worms as there are heads.

Of the wheel-animalcules (Rotifera), so common in

FIG. 99 Pleurobrachia

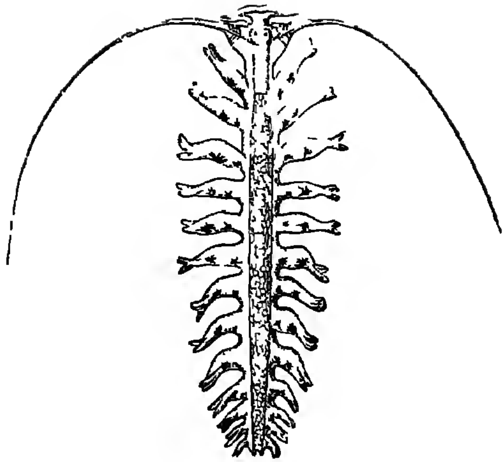


FIG 100 Tomopteris

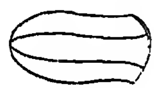


FIG 101 Beroe

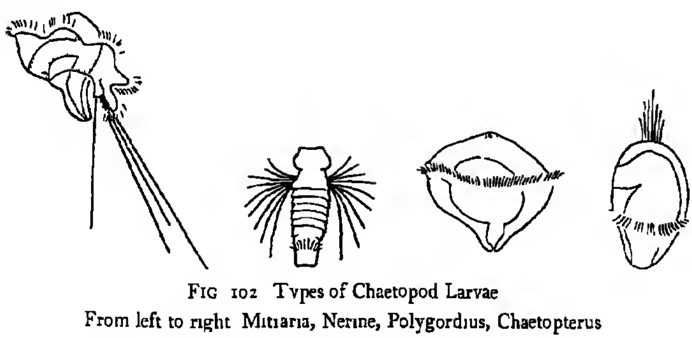


FIG 102 Types of Chaetopod Larvae
From left to right Mitraria, Nerine, Polygordius, Chaetopterus

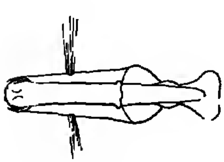


FIG 103 Spadella

FIG 104 Sagitta

fresh water, some seventy species are stated to be marine; little is known of them.

The little glass-arrows, or Chaetognatha, are of constant occurrence, apparently in all seas; they vary in length from ½ in. to 4 in. (Figs. 103, 104).

The group to which crabs, lobsters, and so forth belong —the Crustacea—are probably more plentiful than any other in plankton. Of the 'water-fleas' (Cladocera), minute animals with two shells, a large pair of rowing antennae, and one large eye, some are not infrequently taken (Evadne, Fig. 105). Another subdivision of Crustacea, also with two shells, is termed the Ostracoda, one family of which is sometimes very abundant (Conchoecia, Figs. 106, 107).

Probably the most widely spread and prolific group of the whole Animal Kingdom, so far as plankton is concerned, is formed by the 'oar-footed' Copepoda (Figs. 108–111), which are only very rarely, if ever, absent from a haul; generally minute, they are active swimmers; they have been met with in such abundance as to give the sea a reddish tinge. When magnified, many show brilliant colourings, due either to iridescence (Sapphirina, Fig. 111) or to the presence of drops of coloured fat. Many of the 'fish-lice' belong to this group; some are only temporary parasites, and can swim (Fig. 108); others embed themselves in the flesh of fish and other creatures, and become so altered, in adaptation to a parasitic existence, that only a study of their development shows them to be Copepods, or, indeed, Crustaceans at all. The Barnacles, or Acorn-shells (Cirrhipedia), are not properly planktonic, but may be found attached to floating weed, driftwood, &c. These have free-swimming larval stages, enclosed in two shells, like an Ostraçod.

The subdivision of Crustacea, which includes the 'sand-

hopper' and the so-called 'fresh-water shrimp' (the Amphipoda), although far more plentiful on the bottom, has representatives (Fig. 112) in the plankton. Some of them

FIG. 105
Evadne

FIG. 106. Conchoecia
(Left Shell and Antenna)

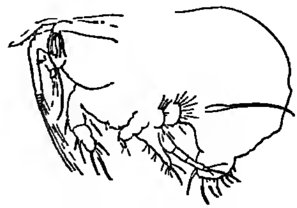


FIG. 107. Conchoecia
(Shell removed)

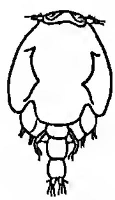


FIG. 108. Caligus

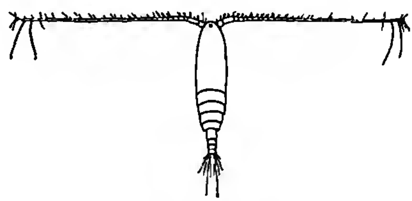


FIG. 109. Calanus

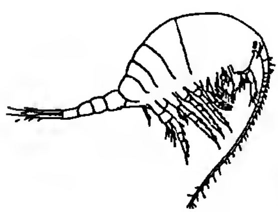


FIG. 110. Temora

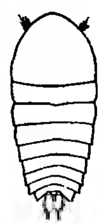


FIG. 111.
Sapphirina

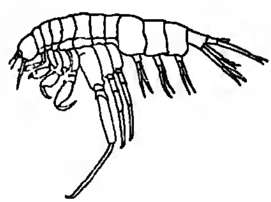


FIG. 112. Euthemisto

haunt the bells of jelly-fish, presumably for protection, while others (Phronima, Fig. 113) establish themselves in the hollow skin of Doliolum (see p. 229). Very closely allied to these is the subdivision which includes the common wood-lice or pill-bugs; these are not insects, as is

generally thought, but belong to the subdivision Isopoda; they may generally be distinguished from the previous subdivision by being flattened from above downwards, while the former are flattened from side to side. Few of them occur in plankton on the high seas, except as parasites, either temporary or permanent (Fig. 114).

The 'opossum-shrimps' (Schizopoda), so called from the brood-pouch present in some species, are frequently taken. Several have special luminous organs, provided with lens and reflector, in different parts of their bodies (Fig. 116). The subdivision, which includes the lobster and shrimp, is termed Macrura—the 'long-tails'; few of these are planktonic when adult, but some prawn-like forms are widely found. Mention must be made, however, of the curious little Sergestids (Fig. 115), not only because they are often captured, but also because of their curious larvae (Fig. 117). Less adapted to a swimming life are the Brachyura, or 'short-tails', of which the common crab is a member; some can swim a little, and one at least has been found in quantity about 200 miles from shore over very deep water. Crabs are also found attached to gulf-weed and other floating objects.

The larvae of Crustacea are often even more numerous than the adults. Most marine Crustacea hatch out of the egg in the form called a Nauplius, which may be known by a shield-shaped body, a single eye, and three pairs of limbs (Figs. 119, 120). This larval stage moults or sheds its skin repeatedly, not only growing, but also changing its shape somewhat at each moult, until it attains the parent form.

Many of the higher Crustacea, after passing through the Nauplius stage, gradually attain a Zoëa stage, which may be recognized by the limbs of the forepart of the body having sprouted, by a pair of large eyes having

Fig 113 Phronima

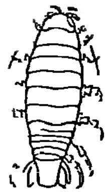


Fig 114 Cirolana

Fig 115 Lucifer

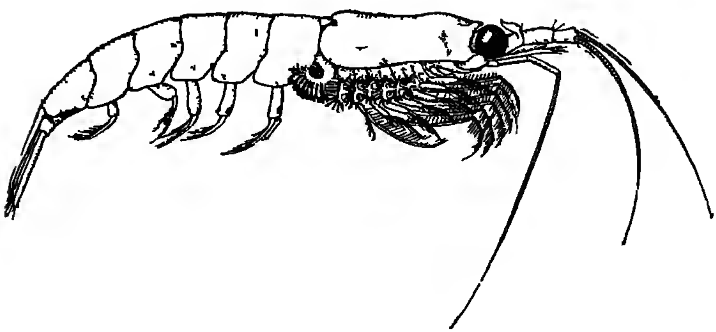


Fig 116 Nyctiphanes

Fig 117 Sergestes Larva The right side of this figure is of the dorsal or upper surface, on the left side is drawn the ventral or under surface to show the limbs

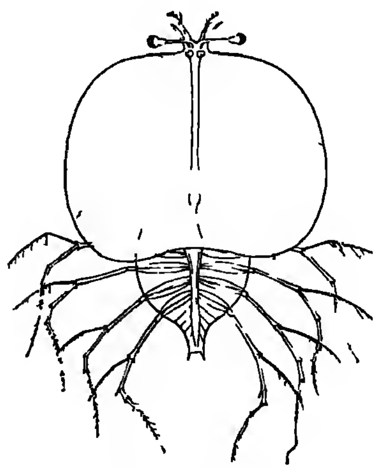


Fig 118 Phyllosoma

appeared, and by the tail part of the body having grown out; the latter carries no limbs, except sometimes the last pair (Figs. 121–3).

A few families have special larvae, which are often common near shore after the breeding season. Thus the crawfish, or spiny lobster (Palinurus), passes through the remarkable stage Phyllosoma (Fig. 118); the crabs, after their Zoëa stage, assume the form known as Megalopa before tucking in their tails (Fig. 124); and the Stomatopoda have a set of larvae peculiar to themselves (Figs. 125–6).

Of the group to which oysters, snails, and cuttle-fish belong, the Mollusca, some subdivisions occur in plankton.

The oyster-forms, or Lamellibranchs, possessing two shells, are occasionally represented by larvae (Fig. 127). The snail-forms, or Gastropoda, are frequently met. Janthina, a warm-water snail, sometimes thrown on our western shores, has a purple shell; to its foot is attached a raft, on the underside of which the eggs are embedded. Atlanta (Fig. 128) has a spiral shell, with a narrow keel; Carinaria, like a transparent slug, carries a shell on its hump (Fig. 129); very like it, but without shell or hump, are several other warm-water forms. The pteropod, or 'wing-footed' forms, are found in all seas; of these the majority have shells (Figs. 132, 133). Near-shore larvae of Gastropods are often plentiful; the most characteristic is the 'Veliger' stage (Fig. 130).

The cuttle-fishes, of which the octopus and squid are too well known to require a figure, are all more or less planktonic, although many, especially in shallow water, are bottom feeders; they sometimes attain a huge size. Some have a web between the arms, which thus form a great funnel. Any forms with an external shell (except the familiar Pearly Nautilus and Argonauta) should be

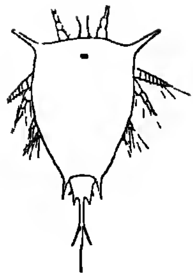


Fig 119. Nauplius Larva of a Barnacle

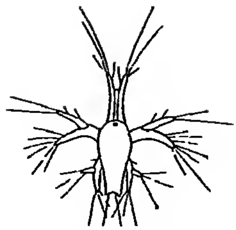


Fig. 120. Nauplius Larva of Penaeus

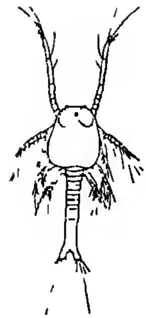


Fig. 121. Zoea Larva of Penaeus

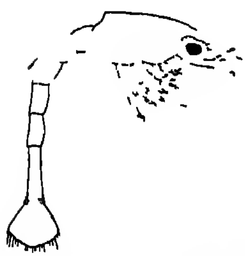


Fig. 122. Zoea of Callianassa.

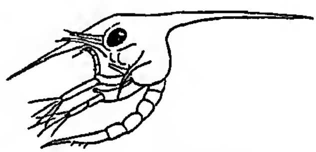


Fig. 123. Zoea of Thia

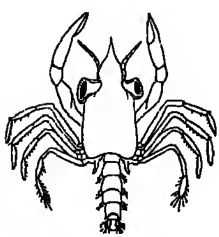


Fig. 124. Megalopa Larva of a Crab

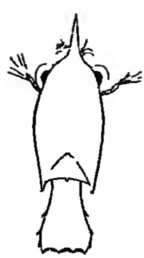


Fig 125. Early Larva of a Squilla

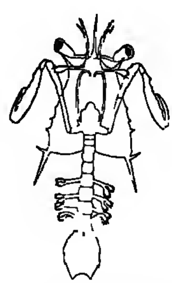


Fig. 126. Late Larva of a Squilla

carefully preserved for study by experts, such as the body of the little Spirula, the dead shells of which are not uncommon in eastern seas.

Of the group of Echinoderms—the starfish, brittle-stars, sea-urchins, trepangs, sea-lilies—a single adult genus only has as yet been taken in plankton, but their larvae are frequently captured; these are even more unlike their adult form than in the Crustacea. The adult form in Crustacea was attained by a series of moults, but in the Echinoderms it rather grows out of the larvae, which, so to speak, shrivels down on to it. Each of the five sub-divisions has its own type of larvae, four of which are here shown (Figs. 135–42).

Of the enormous group of Insecta, only one small family is truly planktonic (Fig. 134).

Of the Polyzoa (they have no English name), none are found in plankton, except accidentally attached to drift-wood or weed. Near shore their larvae are common; of these, the most likely to strike the eye has a shell like a flattened funnel (Fig. 131).

The foregoing groups are all taken from the inverte-brate animals, but there remain some creatures, very common in plankton, which only a naturalist would dream of classing anywhere near vertebrates. Yet these animals, both by structure and development, are undoubtedly akin to vertebrates; they have (among other characteristics), either when larval or throughout life, a supporting rod in the back (the notochord), exactly like that of a sturgeon or lamprey, or the similar rod round which the vertebrae are moulded in the embryos of all vertebrates, including Man. The names of these groups refer to this notochord.

The 'sea-squirts' and salps are included in the group Urochordata—i.e. with the notochord in the tail. Some of them retain it throughout life; for instance, Appendi-

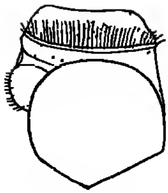


FIG. 127. Oyster Larva

FIG. 128. Atlanta

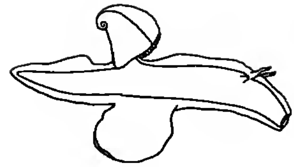


FIG. 129. Carinaria

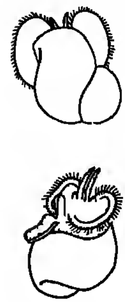


FIG. 130. Veliger Larvae: above, Dorsal; below, Ventral

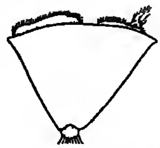


FIG. 131. Larva of a Polyzoan

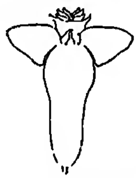


FIG. 132. Clione

FIG. 133. Shelled Pteropods: above, Hyalea; below, Styliola

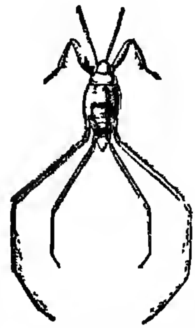


FIG. 134. Halobates

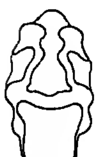


FIG. 135.

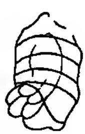


FIG. 136.

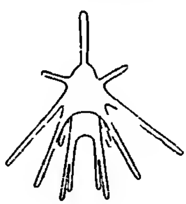


FIG. 137.

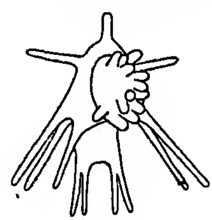


FIG. 138.

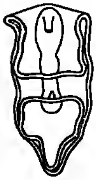


FIG. 139.

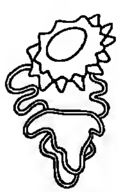


FIG. 140.

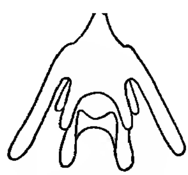


FIG. 141.

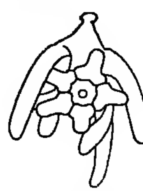


FIG. 142

FIGS. 135. Auricularia Larva of a Holothurian. 136. The same, later, the young Trepang showing. 137. Pluteus Larva of an Echinoid. 138. The same, later, the young Sea-Urchin prominent. 139. Bipinnaria Larva of an Asteroid. 140. The same, later, carrying the young Starfish. 141. Pluteus Larva of an Ophiuroid. 142. The same, later, with the young Brittle-Star.

cularia (Fig. 143), which can often be captured in this country in an estuary on a flowing tide; some species form temporary 'houses' of jelly-like material. Others drop the tail and notochord on assuming the adult form; of these Pyrosoma (Fig. 144), brilliantly luminous, as its name 'fire-body' implies, is a colony of animals embedded in a common cylinder of jelly, mouths outwards. A solitary form, Doliolum, is remarkable for its complex life-history; the form, A (Fig. 145), itself developed from a fertilized egg, gives rise to little buds, which wander up on to the projecting horn behind their parent, and arrange themselves in three rows. Those of the side rows, B, grow into a spoon-shape, and act as food and water pumps for the rest (Fig. 146); large buds of the middle row, C, presently break off (Fig. 147), carrying on their broken stumps tiny buds, which also belong to the middle row. These grow up into the sexual form, D (Fig. 148), and break away in their turn; their eggs begin the cycle anew. Even more complex, and not yet fully understood, is the life-cycle in two similar forms. Specimens of all such from tropical seas should be carefully preserved for study by competent hands.

Another subdivision is represented by Salpa. In this, an animal which has developed from the egg, buds off a chain of little Salps; first the chain, then the separate individuals are detached, become sexual, and produce eggs, and the life-history begins again (Figs. 149, 150).

A second group is formed by the Hemichordata, in which the notochord is only partly developed; none are planktonic, but one (Balanoglossus) has a planktonic larva, which is not uncommon.

Lastly, in the group Cephalochordata (Amphioxus), in which the notochord extends to the tip of the head, the

adult, in shape rather like a fish, lies half buried at the bottom, but the larvae are planktonic.

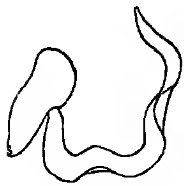


FIG. 143. Appendicularia

FIG. 144. Pyrosoma

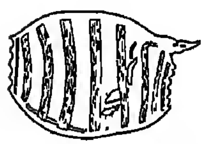


FIG. 145. Doliolum. A. The nurse form which buds B, C, D.

FIG. 146. Doliolum B. The spoon form.

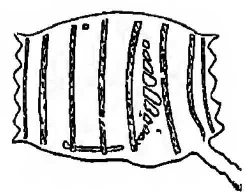


FIG. 147. Doliolum. C. The wandering form carrying buds of D.

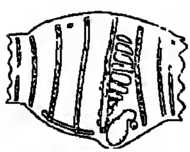


FIG. 148. Doliolum. D. The sexual form.

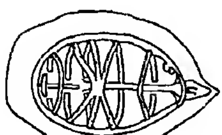


FIG. 149. Salpa. The sexual form.

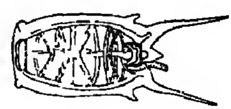


FIG. 150. Salpa. The budding form with a chain of little salps hanging out

Excluding the fish, which are the subject of a separate chapter, the animals above described may be taken to represent fairly completely types of the forms which are likely to be captured at or near the surface.

Methods of Capture

The next question is, how to catch them. The net, termed a tow-net, consists of the frame, the net, and the tin. The net about to be described is suitable for any one wishing to sample the contents of the sea, either from a rowing-boat or a small motor-boat. The frame is best made as follows; from an oil-shop procure a stout 10 foot length of flexible cane, such as is used to poke down drains; a sharp bend in it may be taken out on soaking the bend in boiling water. When straight, twist this up into a circle of about 2 ft. in diameter and lash the ends in with strong cord or copper wire.

The net is best made of Swiss silk (called bolting cloth, such as is used for sifting fine flour). This material is very expensive, and if cost has to be considered, a muslin net can be used, but it is not so lasting, neither are the meshes so regular or clear of fine fibres, and they are more liable to become clogged up. A muslin net is quite serviceable providing that it is well cleaned out after use; silk nets must be dried directly after use, or else they will very quickly rot.

A useful all-round sort of net has 60 meshes in a linear inch. The small net with a glass tube at the end used by pond-life collectors is useless for sampling the sea. The organisms are not so concentrated as in small ponds. A much larger net has to be used and a convenient size for general purposes is about 1½ ft. in diameter at the mouth, tapering gradually down to 4 in. at the bottom, where the tin is tied on, and about 5 ft. in length. Care should be taken to fold the material so that it makes, when cut out and sewn up, a perfect cone, if wrongly folded and sewn the net becomes lop-sided. At the top and bottom the net is sewn on to a stout band of broad tape or on a strip

of calico; to the top band are sewn short pieces of tape to tie the net on to the cane frame; through the bottom band should pass, in a plait, a running cord which will gather it securely over the tin. The 'tin' is best made of copper or zinc with a rounded flange round the mouth, below which the running cord grips, and large enough to hold about a pint of water. From the frame run three 'bridles' of stout line, about 3 ft. long and spliced together where they meet; to these is attached the tow-rope. For the latter a stout hemp line is best, if too thin it cuts the hands when wet.

When tow-netting near shore from a small boat, a small net usually meets all requirements, it can be sent down to near the bottom by attaching a lead weight near the bridles and is easily hauled in by hand. For such work as is carried out at Marine Biological Stations and on Expeditions more elaborate methods of tow-netting are used, such as fastening several nets at different depths on a wire rope with a heavy weight at the end, or having large and special nets designed for research work. Such methods can only be carried out in a satisfactory manner on ships properly equipped with the necessary gear for lowering and hauling in heavy nets, and also having some one in charge who has had the required training, or the nets will soon be found round the propeller.

The net should be towed very slowly, but both pace and mesh are decided by the kind of animals which one hopes to catch. With a net about 1½ ft. in diameter one should be able to hold the tow-rope on one finger; a reasonable pull should be about three pounds against a spring balance. The secret of successful tow-netting is the pull on the net. A good catch depends much upon the slow filtering of the water through the meshes of the net. When the pressure of the water inside the net is much greater than the pressure outside it, the net becomes more

or less waterlogged and the organisms instead of entering the mouth of it shoot over its edge and thus escape capture. The same result happens when a dirty net is used or the meshes have become choked with diatoms. The net ceases to filter properly and becomes waterlogged, then one might as well tow along an iron bucket. By tow-netting slowly with just enough pull to keep the net properly extended the animals are caught uninjured, for they pass slowly down inside the net into the tin. It sometimes happens that the pull is not sufficient to keep the net in a horizontal position or properly extended, it sags down owing to the weight of the tin. This can be easily remedied by tying some corks round the tin. A twenty minutes haul is generally long enough, after this the net should be hauled in very gradually, otherwise the pressure of the water against the meshes seriously damages the more delicate animals.

As soon as it arrives on board, the contents of the tin should be emptied, with plenty of extra water, into a big glass bottle—a wide-mouth pickle-jar or sweet-jar is excellent. The larger animals can be picked out with a lifter (an old tablespoon, the bowl bent at right angles to the shank, serves the turn). For those of smaller size, take a glass tube, about 8 in. long and $\frac{3}{8}$ in. outside diameter, hold this between thumb and middle finger, stopping the upper end firmly with the first finger; lower it thus over the animal, remove the first finger, and animal and water will rush up into the tube. Replace the finger, and the tube with its contents can be lifted out if kept vertical. The animals can thus be transferred to glass dishes and examined, or preserved for future study (see Chapter XI).

In temperate climates most planktonic animals will live for some hours in a glass bottle if absolutely clean and kept cool. In the tropics, where the bottle cannot be kept

cool, they die very soon, and should be preserved as soon as possible.

For immediate examination on board, as a ship is rarely still enough (except in harbour) to allow of the use of a microscope, a small 'dissecting microscope', with simple lenses magnifying about 6 and 10 diameters, is absolutely invaluable.

Naturally enough, the animals in plankton are not always and everywhere the same. In the first place the distance from shore makes a great difference. Plankton from shallow water near land shows numerous larvae of bottom animals, and such jelly-fish as are budded from hydroids, but over deep water such larvae are hardly ever present; there are larvae of planktonic adults, but they are not so numerous in proportion, and these adults are mostly different from those near shore. Hence we distinguish the 'neritic', or coast-wise plankton, from the 'oceanic', or blue-water plankton; the 100-fathom line may be roughly taken as the boundary between them, but they pass imperceptibly into one another. Secondly, the temperature of the water makes a great difference in the plankton; it is fairly obvious that as a rule an animal which can stand arctic cold of 30° to 35° F. will not be happy in the tropics with a sea temperature of 80° to 90° F. (although such cases do exist); but many marine animals seem to be influenced by quite small differences in temperature. Thirdly, if there be too little salt in the water—for example, in estuaries or the Baltic—many species will not live there. Lastly, the character of the plankton alters a good deal with the depth; it is not every animal which can thrive in absolute darkness, at a very low temperature, on such casual food as falls from the surface layers towards the bottom.

This last statement opens up a fresh branch of the subject. Plankton is by no means confined to the upper

layers of water, but has been captured even at the greatest depth to which suitable nets have been lowered (2,734 to 2,187 fathoms). Such nets, termed 'closing nets', are lowered to a known depth, with the mouth closed; they are then opened by mechanical means, towed either vertically or horizontally for a known distance, closed again, and brought closed to the surface; they therefore only contain animals from the desired depth. This mid-water work has been systematically attempted only of late years, and forms a fascinating branch of study. Very little is known at present about the plankton of great depths, and any yacht with a steam winch can do most valuable work in this direction. A description of the necessary outfit is rather beyond the scope of these pages, but details can easily be obtained from the Challenger Society or the Director of the Marine Biological Association's Laboratory at Plymouth. Many of the animals from great depths seem to be confined to deep water, but some are known also from the surface.

Of one branch of plankton we know almost nothing—that is, of those invertebrates which, although capable of swimming a little, are closely dependent on the bottom of the deep sea either for food or for resting. For their capture tow-nets are attached to the trawl-heads or dredge, streaming a little behind them so as to catch the animals disturbed by raking up the bottom.

The plankton, then, is not always the same everywhere, but the reasons why it is different in different places are only partly understood; it seems, however, certain that the temperature has more to do with this than anything else. Some species seem able to stand much greater extremes of temperature than others; but for every species there is a (maximum) temperature above which it cannot live, a (minimum) temperature below which it cannot live,

and an (optimum) temperature at which it thrives best. To take a well-known case, characteristic animals of the Gulf Stream and North Atlantic Drift rarely reach as far east as our islands, although the actual water in which they lived travels as far as the North Cape; they die out as the temperature falls. The slaughter is particularly heavy where hot and cold currents meet.

Supposing that we knew precisely the maximum and minimum temperatures of a species—say 60° and 45° F. for a north Atlantic species—then by drawing lines on the map through all the points where 60° and 45° F. occurred at the surface, we could run a surface boundary round the animal, and map its 'horizontal distribution'. Further, if this species can tolerate so low a temperature as 45° F. at the surface, there seems to be no reason why it should not live at 45° F. at any point below the surface; consequently, in addition to the horizontal distribution, we want to be able to map also the distributions at different depths, and thus the space occupied by the species will form an irregular figure in three dimensions, with length, breadth, and thickness. Unfortunately, in the present state of knowledge, we are unable to draw this figure with certainty for any single species; hence it will be readily understood how important it is always to record the temperature of the water from which a haul is made, and, if practicable, also the salinity.

One interesting result of the ability of many animals to live below the surface, provided that they keep above their minimum temperature, is that some arctic species are continuously distributed from pole to pole in the deep cold water of mid-ocean; but have never been captured anywhere near the surface in the tropics, where the temperature is above their maximum.

A comparison of the organisms taken in nets at the

same time and place, but at different depths, has favoured the view that some come to the surface at night and sink to some depth during daylight as a protection against too bright light. It is only recently that series of observations have been made to investigate thoroughly this interesting point. They have been carried out by the staff of the Marine Laboratory at Plymouth, with a special large net, about six feet in diameter and a reliable depth self-recording instrument used. The results clearly show that certain animals do come to the surface at night and sink to a definite depth during daylight. Some living close to the bottom ascend at night towards midwater and become more uniformily distributed, whereas others are quite indifferent to the intensity of the light. This vertical distribution is found in nearly all the animal groups, but only certain species are affected. These show an ordered vertical distribution during a full summer's day and different species segregate at different depths, each having its own maximum, minimum, and optimum with regard to light intensity, showing that each prefers a definite light intensity where most specimens will be found (optimum), and a decrease in number towards the light intensity, above which none are usually found, and the same in respect to the minimum light intensity. How far the downward movement goes is at present unknown, but probably not much below 50 fathoms. There is also the possibility of its being checked by the fall in the temperature of the water, to which most organisms are sensitive.

There is also a seasonal change in the depth due to the intensity of sunlight in the different months of the year, the optimum depth would thus be nearer the surface in winter than in summer. The depth therefore depends upon the intensity of the light prevailing at the time, varying day by day and month by month.

This vertical distribution of the plankton is an important point to keep in mind when tow-netting in the open sea and where the water is deep. The specimens wanted may not be near the surface, but say at 20 fathoms, so it is advisable when using only one net either to sink it deep and haul it in by stages to the surface, or to take several hauls at different depths. Where currents run strong the vertical distribution does not occur, as here there is too much of a general stir up taking place.

Hauls may be readily compared if standardized—that is to say, if they are made with nets of similar mouth, length, and mesh, for the same time, and at the same speed of towing. In this case all that is necessary is to preserve the whole catch, and to count the specimens of any species under study; thus it can be readily shown in accurate terms that a species is rare at the one hour, depth, date, or place, and common at the other. Every haul made for comparative work (and that is pre-eminently the work now required) should be made with standard nets, time, and speed. The only thing difficult of control is the speed, except in a small launch, but this can be read by a current meter. Standards are suggested on p. 240.

As a rule, the greater number of the species captured at or near the surface at any particular position at sea will be found to extend to about 100 fathoms at that position (not necessarily elsewhere, where the temperature and other conditions may be different). For a proper study of the alleged up-and-down movements of the plankton, and for many similar objects, it is desirable to know, not only whether it is rarer or more abundant at the surface under certain circumstances, but also where it goes to when not at the surface. The method of hauls with open nets at various depths will throw a good deal of light on this, but these nets are not to be trusted absolutely, because they catch

specimens from higher levels while being hauled to the surface. For accurate work a closing net should be used horizontally, lighter and smaller than those used for true deep mid-water work; they should carry the same standard net, and be used for standard time and at standard speed.

Other points requiring study by similar methods are the supposed movements of plankton due to rain, breaking seas, wind, fresh water from large rivers, floating ice, and so forth.

A curious feature well worth attention is the way in which plankton becomes concentrated into swarms or streaks; it is by no means universally distributed, even over a small district. Such streaks should be surveyed, if possible for dimensions both horizontally and vertically. Particular attention should be paid to the comparative abundance of plant food inside and outside the area, as well as to their position as regards current and tide, for it has been suggested that they are formed exactly as a river throws raffle on its banks.

All special adaptations of a planktonic organism to its conditions of life should be noted. A striking series of these adaptations is naturally directed towards preventing weak swimmers from sinking. This object is attempted in various ways, of which the chief are—either (*a*) a diminution of weight by the formation inside the animal of light fluids (in the bubbles of Foraminifera and Radiolaria), fats (Copepoda), jelly (Jelly-fish and Salps) or gas (Siphonophores); or (*b*) an increase of surface in order to increase the friction in falling through the water, produced either by flattening the body (Phyllosoma, Sapphirina) or the growth of long spines (Foraminifera, Crustacean larvae).

Coloured sketches from life are always valuable away from home waters. Most of the larger invertebrate plankton

is nearly colourless and transparent, and any exceptions to this should be noted, and, if possible, sketched.

Round our own coasts there is much to be learnt of the daily and seasonal movements of the larger plankton, and of its behaviour under changing conditions of its surroundings. Once clear of European coasts, a traveller may feel certain that his collection of plankton will be serviceable to science if accompanied by proper observations and full notes.

What the study of plankton requires nowadays is not the mere collection of specimens, but the collection of facts. Naturalists have described thousands of planktonic animals from all sorts of places, but know very little about how they came there, why they are there and not elsewhere, how they live, what they eat, and what eats them. Without such knowledge the study of plankton is about as interesting as to read a street directory containing solely names and numbers. Consequently every item of what is called 'natural history' should be observed and noted, and every possible detail recorded whenever a haul is made. The routine details are set out in the sample General Log (p. 462), subject, of course, to modification for special cases.

Except when an observer is simply collecting plankton for his own instruction (if even then), no haul should be taken without a definite object; it should have a story to tell of the plankton of a particular place, hour, depth, or season, of the effect of rain, breaking sea, ebb and flow of tide, and so forth. For the study of all general questions, the hauls should always be standardized as suggested on pp. 237 and 240.

It will be seen readily from this brief sketch that plenty of interesting work awaits any one who has opportunity and a tow-net. In harbour, from a pier or reef of rocks if the tide serves, from a small boat or a big ship, the tow-

net can be streamed with the certainty of an interesting result; even if the catch be scanty, the result becomes of value if the reason for its scantiness be found. No observation, however apparently insignificant, is scientifically worthless if it be securely based on fact. On however small a scale, valuable work may be done for science without attacking the more intricate problems. The simple tow-net haul in foreign parts, if accompanied by the necessary observations, will always be worth making, preserving, and submitting to experts for report.

Finally, a word of advice to the beginner who wishes to collect for his own instruction, and to do serious work; he will be at first bewildered with the wealth of life at his disposal, and depressed with the difficulty of finding what is already known, what not. Let him therefore confine himself strictly to the animals of one, or at most two, groups, and hand the rest over to an expert at home; let him select for his own study the group or work to which he feels most attracted and interested in. Then work is no longer a toil but a real pleasure.

NOTE.—The International Council for the Exploration of the Sea have recently[1] recommended the adoption of standard nets for vertical and horizontal hauls. These nets are specially adapted for closing, but it will be sufficient for the purposes of the general collector if they are used as non-closing nets. The dimensions laid down are: 1. *Net*, length 2 m., diameter at mouth 50 cm., diameter at tin 10 cm., breadth of calico at top 3–4 cm., at bottom 8 cm.; 2. *Frame*, a ring of 5/8 in. iron, 50 cm. in diameter; 3. *Material*, Bolting Silk No. 25, 77 strands to 10 mm., for the fine-meshed net; and No. 3, 23 strands to 10 mm., for the coarse-meshed net.[2]

[1] Ostenfeld, C. H., and Jespersen, P., 'Standard Net for Plankton Collections'. Conseil Permanent International pour l'Exploration de la Mer. Publications de Circonstance, No. 84, 1924.

[2] The numbers given here are those used by Albert Wydler, the manufacturer of the silk at Zürich. This material can also be obtained from Messrs. Stanniar of Manchester, and corresponds to their numbers 200 and 58.

VI

THE SEA FLOOR

BY THE LATE SIR JOHN MURRAY (1912)

Methods

THE oldest method of sounding was by means of the hand-lead, usually 12 to 14 lb. in weight, 'armed' with lard or tallow, to which a sample of the bottom adheres, and with a line marked in fathoms and fractions of a fathom. Practically all the coasts of the world have been surveyed by instruments of this kind used from rowing-boats. When attempts were made to sound in 100 or 200 fathoms, heavier weights and more carefully prepared hempen lines were employed, and the leads were provided with cups, valves, or snappers, to bring up samples of the sands, gravels, and muds. Sir James Clark Ross, during his Antarctic cruise (1839 to 1843), made most praiseworthy attempts to sound the greater depths of the ocean with ordinary sounding lines and heavy weights from small boats. He succeeded in recording depths down to 3,600 fathoms, but, although the time each 100 fathoms left the reel was noted in the usual way, he was uncertain when the weights reached the bottom, and the results were not altogether trustworthy. About the year 1854 Lieutenant Brooke, of the United States Navy, introduced the method of detaching a heavy weight from the sounding-tube on its striking the bottom; henceforth deep soundings were recorded much more frequently and with greater accuracy, while good samples of the deposit were obtained.

During the *Challenger* Expedition (1872 to 1876) sounding with wire had not passed the experimental

stage; all that was known for certain was that the same wire could not be used for many soundings without breaking. The *Challenger* made use of a specially made hempen sounding line. It had to carry on each occasion a load of valuable instruments, and in this it was brilliantly successful. Wire rope is suitable for sounding pure and simple; indeed, the systematic investigation of the form of the bottom of the ocean can only be rapidly carried out with wire. For deep sea researches, where many valuable thermometers and other instruments must be sent to the bottom in deep water, hemp rope is much more trustworthy than wire. However, during the recent *Michael Sars* Expedition in the north Atlantic a six-strand wire 3 or 4 mm. in circumference was used, with excellent results, to carry several thermometers and water-bottles down to depths of over 1,000 m.

In the ordinary routine on board the *Challenger* the soundings were made with the Baillie machine (see Fig. 151), the sinker weighing 336 lb., the tube 25 lb., and the attached water-bottle 20 lb. The effective sinking-weight was 333 lb. in water; every 100 fathoms of line used in sounding added 6 lb. to this effective sinking-weight. In very shallow water there was acceleration in the rate of descent, but in deep water there was continual and progressive retardation. With wire there is continuous acceleration if allowed to run free like the hemp line.

In recent years soundings have been made by various types of wire sounding machines, such as the Le Blanc, the Sigsbee, and the Lucas. The Lucas machine (Fig. 197, p. 321) is the one most frequently in use, and is extremely satisfactory. It seems unnecessary to describe these various instruments in detail; their great advantage is that they indicate at once when the weight strikes the bottom. In well-appointed cable ships soundings in 2,000

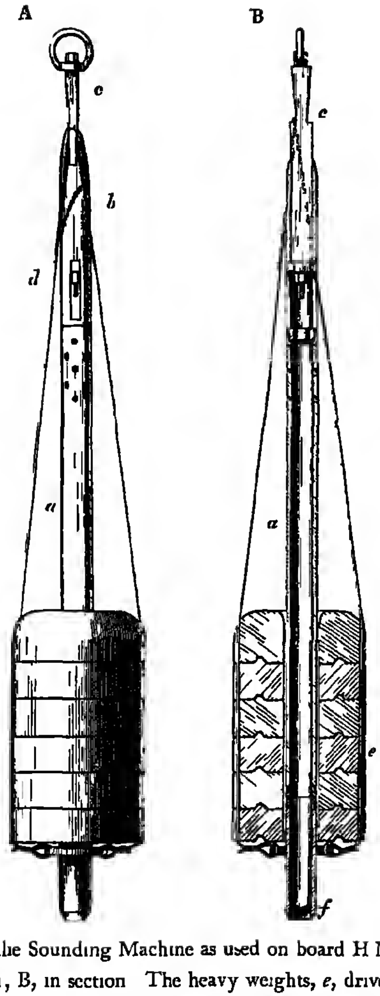


FIG 151 Baillie Sounding Machine as used on board H M S *Challenger*

A, in elevation, B, in section The heavy weights, *e*, drive the central tube, *a*, into the bottom deposit, and the ooze is retained in the tube by the butterfly valve, *f* As soon as the suspension is relaxed, the shoulder carrying the wire which holds up the heavy weights becomes sheathed, the wire and weights being left at the bottom

fathoms can be made in an hour from start to finish, but in order to do this the wire must be hove in as fast as possible, and breakages of the wire frequently occur. One cannot, therefore, work at this rate with any regard to the safety of instruments attached to the wire. With hempen line the maximum rate of working can be observed, even when the line carries instruments. On cable ships there is usually plenty of old or damaged wire, and where the depth only is required, this old wire is sometimes used and cut adrift when the bottom has been reached in order to save the time of heaving it in.[1]

A great many arrangements have been used with the sounding apparatus to bring up samples of the deposits forming on the bottom in deep water. The 'arming' of the hand-lead with lard and tallow has already been mentioned; snappers, cups, and tubes with valves are also used for this purpose. Experience alone can show the best appliance to adopt in special circumstances. On board the *Challenger*, when sounding over Red Clay areas, the Baillie sounding tube, 2½ in. in diameter, without butterfly valves, has been forced from 18 in. to 2 ft. into the deposit, and has brought up a section of that depth, the total quantity of clay being more than enough to fill a quart bottle. So far as obtaining a sample of the bottom is concerned when sounding, this is the most successful record. Sometimes, however, the whole of the mud would slip out of the tube while being hauled up. To prevent this, valves and balls at the upper end of the tube were

[1] Recently a method of echo-sounding has been introduced, whereby sound waves are sent to the sea bottom, from which they are reflected back to the surface. The speed of sound through water is approximately 4,900 ft. per second, varying slightly with salinity and temperature. By this means soundings may be taken very rapidly compared with the old methods, and a ship can steam at full speed sounding as she goes. The German research cruiser *Meteor* has recently undertaken a very large number of such soundings in the South Atlantic.—*Ed.*

used with varying success. In positions where a typical Globigerina Ooze was expected, a butterfly valve was generally inserted in the lower end of the tube, and this arrangement was generally successful in retaining some of the deposit. To place three or four small tubes side by side, without valves, has been found a good arrangement. Gravel and small stones are the most difficult of all samples to recover, and for these the snapper (Fig. 196, p. 318)

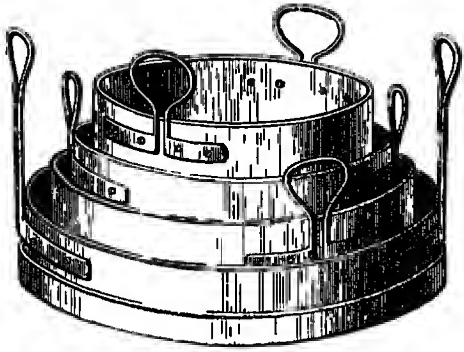


FIG. 152. Set of Sieves for grading the contents of Dredge or Trawl, or material gathered on shore
For use the whole set is immersed in a tub of sea-water

and the 'Rendle tube' are the most successful. During the *Michael Sars* Expedition (1910) a heavy contrivance of Nansen's was successfully used to bring up a section of the deposit, but this entailed a stranded wire and a separate sounding operation.

In the dredge and trawl large quantities of the deposits were sometimes brought to the surface, and a careful examination of these threw a great deal of light on the samples procured by the sounding machine. Large samples of mud, ooze, or clay, were carefully passed through wire sieves (Fig. 152) with different sized meshes, and these coarse and fine 'washings' were carefully

preserved for future examination. It has often been regretted that larger samples procured in the dredge were not preserved and brought home without being passed through sieves.

The samples of deep-sea deposits which are procured are best preserved by being at once placed in wide-mouthed glass-stoppered bottles, and a small quantity of methylated spirit can be with advantage added, although this is not essential. Cork-stoppered bottles and tubes can also be used. Spirit, added to the samples which contain sea-water, will throw down some of the sulphate of lime, in a gelatinous-like condition (Bathybius), but this is not a very serious objection. When a roll of the deposit is procured from the sounding tube, it should be surrounded with blotting-paper, or pushed out on to blotting-paper; the whole can then be enveloped by the paper, dried, and retained for future detailed examination. The colour of the sample and any other peculiarities should be carefully noted in the wet condition. A label should be put on the outside of the bottle or tube (not on the cork), as well as inside.

The Depth of the Ocean

The ocean has now been sounded in nearly all directions, and our views as to the relief of the sea floor are slowly becoming more and more definite. It is often asserted that we know very little concerning the depth of the ocean, so few are the soundings compared with its vast extent. It is possible to underrate the extent of our knowledge in this respect, for if the extent of the ocean be great, it should be remembered that the uniformity of the conditions is also great over wide areas. Notwithstanding the great number of deep-sea soundings recorded since 1895, when the depth-hemispheres in the final volume of the *Challenger* reports were published, it is somewhat

remarkable that the contours shown on these have been comparatively little altered in their broad general outlines, although many deeps and submarine elevations have been discovered in recent years, and in some regions the contour-lines now represent a much more complicated appearance.

These depth-hemispheres have been kept up to date by Sir John Murray and Mr. J. G. Bartholomew. An inspection of the reduced chart given here will show at a glance where deep soundings are most abundant.

The greatest depth yet recorded in the ocean is 5,269 fathoms (9,636 m.), or 66 ft. less than six English miles.[1] This was a sounding taken by the U.S.S. *Nero* in the Challenger Deep to the south of the Ladrones, where the *Challenger* recorded a depth of 4,575 fathoms. Depths greater than 5,000 fathoms are also known in the Aldrich Deep in the south Pacific. There are altogether ten deeps in which depths exceeding 4,000 fathoms have been recorded, two of these being in the Atlantic, and the remainder in the Pacific. The term 'deep' is limited to those parts of the ocean in which soundings of 3,000 fathoms or deeper have been taken. On the depth hemispheres above referred to, fifty-seven deeps are now shown —thirty-two in the Pacific, eighteen in the Atlantic, five in the Indian Ocean, and two in the Southern Ocean south of latitude 40° S.

From the data at present available the depths over the total floor of the ocean are now estimated as follows:

Between shore line and 100 fathom line	7 per cent.
" 100 fathom line and 1,000 fathom line	9 "
" 1,000 " " 2,000 " "	19 "
" 2,000 " " 3,000 " "	58 "
Over 3,000 fathoms	7 "

[1] The greatest depth now recorded is in the Pacific off Mindanao, in the Philippine Islands, and is 5,348 fathoms.—*Ed., Oct. 1928.*

It will be seen from the above that the extent of the sea-bottom lying between the shore line and a depth of 100 fathoms (600 ft.) is very nearly equal to the area lying between 100 fathoms (600 ft.) and 1,000 fathoms (6,000 ft.). The first area is known as the continental shelf, and is regarded as belonging to the continental areas. Many portions of it were evidently dry land at no very remote geological period. Deep ravines frequently cross the continental shelf, and are believed to be submerged river valleys, which in some cases can be associated with still existing rivers—for instance, the Rhine and the Congo. The materials which cover the continental shelf are to a large extent under the influence of waves, tides, and currents, and are constantly subjected to transport by these agencies. It is believed that waves or currents do not transport other than the very finest particles at depths greater than 100 to 150 fathoms (600 to 900 ft.). In cup-shaped depressions, or sheltered bays within the 100-fathoms line, fine mud may be deposited in relatively shallow depths, but on coasts facing the great ocean basins muddy deposits commence to form at an average depth of 100 fathoms. Beyond that depth the whole floor of the ocean may be regarded as an area of deposition. We have as yet no evidence of transport by currents at these greater depths.[1] The area between 100 fathoms and the next 900 fathoms, it will be observed, covers only 9 per cent. of the whole floor of the ocean. This area is called the continental slope. It represents the sides of the ocean basins, and shows a relatively rapid descent into deep

[1] On the Wyville Thomson Ridge, between the North of Scotland and the Faroe Bank, mud is not deposited at depths of 250 and 300 fathoms. The tidal wave, being here confined, apparently sweeps the top of the ridge at these great depths, and we have evidence of the same phenomenon on the saddle-backs between contiguous oceanic islands, and on very deeply submerged ridges. Further observations in this direction are much desired.

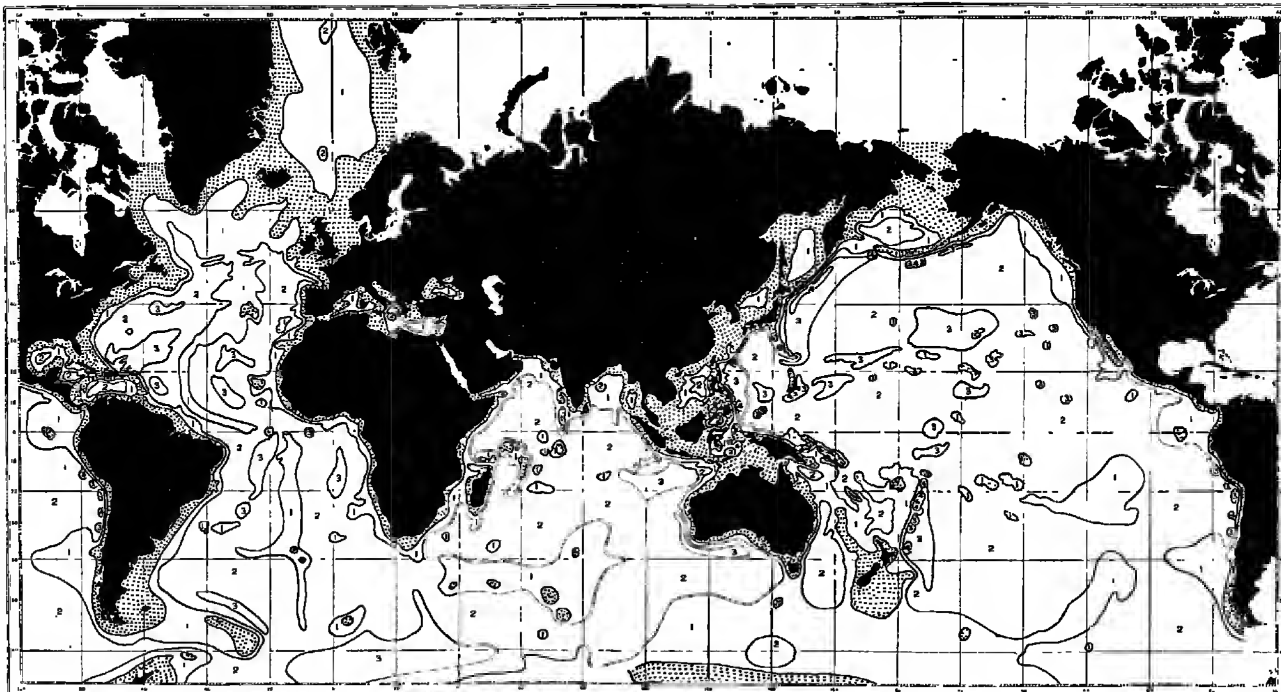


CHART IX.—DEPTHS

Depths of less than 1,000 fathoms are dotted; beyond these a contour line is drawn at every thousand fathoms, the figure 1 meaning 'over 1,000 fathoms', 2 meaning 'over 2,000 fathoms', and so on. The extreme North is left blank (except in the Greenland area) for want of detailed observation

Facing page 248

water; it is the only area of the ocean's floor which can be regarded as concave upwards.

Beyond 1,000 fathoms the floor of the ocean becomes more and more flat and uniform:

84	per cent.	lies below	1,000	fathoms
65	"	"	2,000	"
and 7	"	"	3,000	"

These great submerged plains sink, as we have seen, in some instances to depths of nearly six English miles, and at times they are interrupted by cone-like elevations, some of which do not rise to the surface of the ocean, while others do, and then form groups of volcanic or coral islands. Although a great many soundings have been recorded exceeding 3,000 fathoms, and a great many submarine elevations have been also recorded in recent years, still the general result of recent explorations has been to increase the area of the ocean lying between 2,000 and 3,000 fathoms.

Deposits on the Floor of the Ocean

We have very few indications of the nature of the solid rocks forming the base on which oceanic deposits have been laid down, therefore all fragments of rock from a greater depth than 100 fathoms should be carefully preserved for study. Along some continental coasts fragments have been dredged which indicate an outcrop of tertiary strata. Along some coral atolls solid calcareous rocks have been torn from larger masses, and off both coral atolls and volcanic islands fragments of igneous rocks thickly covered by peroxide of manganese have been broken from steep slopes, indicating an outcrop of volcanic rocks.

In the north Atlantic, from a depth of 1,460 fathoms, the telegraph engineers have brought up, by means of the 'Lucas Grapnel', fragments of gneiss which had been

broken off larger masses. These may have come from outcrops of bare rock in place, but more probably they were broken from large boulders of gneiss transported to the position by icebergs.

We have likewise very few indications of the thickness of the deposits now covering the floor of the ocean, or of the rate at which these are now forming. In the North Atlantic, telegraph engineers think there are reasons for supposing that about 1 inch of Globigerina Ooze accumulates in ten years. The rate at which this type of deposit accumulates, where cold and warm currents meet at the surface, is probably greater than elsewhere; and the rate at which terrigenous deposits are laid down near the embouchures of large rivers is evidently greater than that of any other type of deposit. The deep Red Clay of the Pacific Ocean far from land appears to accumulate at an exceedingly slow rate.

The materials which make up oceanic deposits are now fairly well known, but are worthy of much more detailed study. They consist of inorganic and organic elements:

1. Materials of all kinds borne to the ocean by rivers, winds, and floating ice, as well as what is torn from the coasts by waves, currents, and other agencies; these are termed 'terrigenous' or 'earth born'.

2. Materials derived from volcanic eruptions, both submarine and subaerial. Volcanic dust is transported immense distances by the wind. Pumice of various types is worthy of special notice, because its areolar spongy structure, containing cavities filled with gas, admits of very wide distribution, by drifting on the surface of the ocean.

3. Materials of extra-terrestrial origin, which have fallen to the earth from interstellar space, such as cosmic spherules of iron and nickel, and chondrites with lamellar structure.

4. Materials of organic origin may be carried to the ocean by rivers and winds, but the chief source is the hard parts—the shells and skeletons—of organisms which live in the surface, intermediate, or bottom waters of the ocean. These may be composed of lime (calcium carbonate), such as calcareous Algae, Foraminifera, Corals, Alcyonarian and Tunicate spicules, worm tubes, Ostracod and Cirriped shells, Echinoid spines, shells of Molluscs, Polyzoa, bones of fishes and whales, &c.; or they may be composed of flinty (siliceous) spicules and frustules, such as Diatoms, Radiolarians, and Sponge spicules. In these organic remains it is important to distinguish between those which belong to floating or plankton organisms, and those which belong to the bottom-living or Benthos organisms. Generally speaking, it has been found that the remains of plankton organisms predominate in the deposits of deep water far from land, and the remains of bottom organisms predominate in the deposits of shallow waters near shore.

5. In addition to the foregoing there are many substances which may be termed 'chemical' or 'secondary' products. Clayey matter, which arises from the decomposition of pumice, felspars, and other minerals on the sea floor, may be regarded as a secondary product; so also may the manganese nodules so abundant in some Red Clay areas, where the lapilli and bombs of basic rocks thrown out by volcanoes abound; the palagonite and zeolitic materials found in the Red Clay may be placed in the same category. In addition, 'greensand' (glauconite) grains, glauconitic casts of calcareous organisms, phosphatic concretions, sulphate of barium nodules, iron and calcareous concretions, must be classed among the secondary products now forming in the deposits on the sea bed, many of them through the intervention of decaying organic matter and bacteria.

The varied materials just enumerated are distributed very unequally over the floor of the ocean. The terrigenous materials are most abundant along the shores of continents and islands, and in all enclosed and partially enclosed seas. The geological structure of the adjacent land-masses determines the general character of the deposits along the shores and in the shallower waters, especially as regards the inorganic constituents. The deposits off coral-reef shores are, of course, chiefly made up of fragmentary particles derived from the growing reefs. The size of the fragments diminishes, as a rule, as the distance from the shore line and the depth of water increase; but this is not always the case, for in the very centre of the Pacific and in very deep water rounded fragments of pumice have been obtained of all sizes, up to more than 1 foot in diameter. Again, in regions now, or in recent geological times, affected by floating ice, large boulders, and varied rock-fragments have been frequently dredged up hundreds of miles from land. It is known that seals and penguins may transport rock-fragments in their stomachs to great distances. For these, among other reasons, the size of the particles is of little use for the purpose of the classification of marine deposits.

While the detrital matter from continents and islands, and the shells and skeletons of bottom-living organisms, prevail in the deposits near shore and in shallow water, the remains of pelagic or plankton organisms, and chemical or secondary products, prevail in all the deep water deposits far from land. It is a remarkable fact, however, that in areas where the depth is 3,000 fathoms or deeper, hardly a trace of calcareous pelagic shells, such as those of Foraminifera and Pteropods, is to be found in the deposit, although these may be met with in great abundance in an adjacent area where the depth is only 1,500 or 1,000

fathoms. In like manner the skeletons of Radiolaria and the frustules of diatoms are not nearly so abundant in some deposits as would be expected from the numbers captured in the surface-waters of the region. Both calcareous and siliceous remains are dissolved by sea-water, and when they are not specially abundant in the surface waters, they may be very rare in, or wholly absent from, the deposits at the bottom. At other times these remains of pelagic organisms appear to be almost entirely masked by the terrigenous materials, or other organic remains, forming the deposit.

From the above considerations it is evident that the materials which go to form marine deposits vary in nature, abundance, and size, according to the structure of the nearest land, the character of the submarine volcanic eruptions, the distance from the shore line, the depth of water, and the nature of the organisms living on the bottom and in the surface and subsurface waters. After the detailed study of the marine deposits collected by the *Challenger* and other deep-sea expeditions, Murray and Renard proposed the classification on page 255.

It has frequently been pointed out, even by the authors themselves, that this classification is not perfect, but no better has been as yet proposed. It is founded on the dominant element or characteristic aspect of each type of deposit, and attempts to bring into prominence their origin and constitution. There is no sharp line of demarcation between the different types; they all shade the one into the other, and it is often difficult to determine what name should be given to a deposit on the border line between two or three types.[1]

[1] It is essential to be continually on one's guard against sources of error when examining deep-sea deposits. The object in view is to arrive at a true notion of the composition of the deposit as it lies at the bottom of the sea. Sometimes the trawl or dredge may come up filled with fully a ton of manganese nodules, or

For the information of the geologist, physical geographer, and others interested in marine deposits, it is specially important that descriptions should give as nearly as possible the proportions of the various constituents of which the deposit is made up, as well as the size of the mineral fragments. This, it is believed, can best be accomplished by the method adopted in describing the *Challenger* collections, as set forth in the following model:

H.M.S. *CHALLENGER*
Station, 338. March 21, 1876.
Lat. 21° 15′ S.; Long. 14° 2′ W.
Depth 1,990 fathoms.

large and small fragments of pumice, there may be hundreds of sharks' teeth mixed with dozens of ear-bones of whales Some of these may have living Lepas, or Hydroids, or Serpula, or Foraminifera attached to them It has sometimes been supposed that the whole deposit was composed of these remains, it is, however, almost certain that these various objects were embedded in clay, which passed through the meshes of the nets The same may be observed with reference to the phosphatic and glauconitic nodules found in relatively deep water along continental shores In using sounding tubes with butterfly valves, a large proportion of the finer parts of the deposit is sometimes washed out while the tube is being hauled in, and the larger calcareous organisms appear to be more abundant than they really are When a large quantity of deposit is brought up in the dredge or trawl, and passed through sieves, the various constituents are separated, and the different portions have occasionally been described separately, in this way have arisen erroneously the names Orbulina ooze, Biloculina clay, and Coprolitic mud In like manner the finer parts of a Radiolarian ooze have been described as Diatom ooze, and the coarser parts of a Diatom ooze as Radiolarian ooze When the deposit is preserved in water or spirit, the sample is sorted into different layers by shaking, if a portion be taken for description from the upper layers, and another from the lower layers in the bottle, widely different results will be obtained

The best sample for description is that which is taken direct from the sounding tube, and it should be noted whether the sample is taken from the superficial or the deeper layers With the knowledge we now possess it is possible for an expert to tell approximately the latitude, longitude, and depth from which a deposit has been procured When, then, a sample bears a label showing a Globigerina ooze, for instance, from a depth or latitude which does not accord with experience, it raises suspicions of mislabelling This has frequently occurred with samples labelled on the corks, which have been interchanged

GLOBIGERINA OOZE. White, with slight rose tinge, granular, homogeneous, resembling chalk when dry.

Calcium Carbonate (92·54 per cent.). Globigerinidae, Pulvinulina (80 per cent.); Miliolidae, Textu-

MARINE DEPOSITS[1]

1. Deep-sea deposits beyond 100 fathoms.	Red clay Radiolarian ooze Diatom ooze Globigerina ooze Pteropod ooze	A. Pelagic deposits formed in deep water removed from land.
	Blue mud Red mud Green mud Volcanic mud Coral mud	B. Terrigenous deposits formed in deep and shallow water close to land-masses.
2. Shallow-water deposits between low-water mark and 100 fathoms.	Sands, gravels, muds, &c.	
3. Littoral deposits between high- and low-water marks.	Sands, gravels, muds, &c.	

laridae, Lagenidae, Rotalidae, Nummulinidae (1 per cent.); otoliths of fish, Gasteropods, Lamellibranchs, Pteropods, Heteropods, Lepas valves, Ostracods, Echinoderm fragments, Polyzoa, Coccoliths, Rhabdoliths (11·54 per cent.).

Residue (7·46 per cent.). Reddish-brown.

Siliceous Organisms (1 per cent.). Sponge spicules,

[1] Krummel has recently introduced the term 'hemipelagic' for the deep-sea terrigenous deposits, and 'eupelagic' for the pelagic deposits in the above classification ('Handbuch der Ozeanographie', vol i, p. 205, Stuttgart, 1907). These terms have, however, been employed already to express quite other facts.

Radiolaria, imperfect casts of Foraminifera, Astrorhizidae, Lituolidae, a few Diatoms.

Minerals (1 per cent.). Mean diameter 0·06 mm. angular; felspar, hornblende, magnetite, magnetic spherules, pumice, a few manganese grains, bronzite spherules.

Fine washings (5·46 per cent.). Amorphous matter, with small mineral particles, and fragments of scoriae and siliceous organisms.

Remarks. This is one of the purest Globigerina oozes obtained by the *Challenger*, and is almost wholly composed of the dead shells of surface organisms. A few pumice fragments were found in the washings of a large quantity of deposit.

When carbonate of lime is present, the shells and other calcareous organic fragments are determined by microscopic examination. The lime is then removed from the sample by weak hydrochloric acid, and the relative percentages of lime and residue can be approximately estimated by inspection, or determined by a simple analysis. The nature and relative abundance of the clayey matter, mineral particles, and remains of siliceous organisms in the residue can be estimated by microscopic examination. A description of this kind can quite easily be carried out on board ship.

The following is a short description of the principal types of deep-sea deposits:

A. PELAGIC DEPOSITS

1. **Red Clay.** This deposit is the most characteristic, and probably the most widely distributed, of all deep-sea deposits over the ocean's floor, covering a very large portion of the deeper parts of the Pacific. The name is sufficiently expressive of the nature and appearance of

this type of deposit, there being always a considerable proportion of amorphous clayey matter, usually of a reddish colour, passing in some regions into a dark chocolate colour from the abundance of small grains of peroxide of manganese. Usually the Red Clay contains very few, if any, remains of calcareous organisms, but occasionally there may be an appreciable admixture of the shells of pelagic and bottom-living Foraminifera, teeth and otoliths of fishes, fragments of Echinoderms, Molluscs, Ostracods, Polyzoa, &c., and on approaching shallower water in tropical and temperate regions the shells of pelagic Foraminifera become more and more numerous until the Red Clay passes into Globigerina Ooze. The remains of siliceous organisms (Radiolaria, Diatoms, Sponge spicules, arenaceous Foraminifera) may generally be detected; and in some regions where the Radiolarian remains become abundant, the Red Clay passes gradually into Radiolarian Ooze, while in other regions towards the far north and far south the Diatom remains increase in number, and the Red Clay may pass into Diatom Ooze. Among the inorganic elements met with in Red Clay, the most constant and widely distributed is pumice, which occurs in larger and smaller fragments down to the most minute particles, and in all stages of decomposition and disintegration; the minerals found in pumice, like sanidine, plagioclase, augite, hornblende, magnetite, &c., are also present, along with basic volcanic glasses frequently transformed into palagonite. The peroxides of iron and manganese are universally distributed throughout the Red Clay, sometimes as minute grains or coatings, sometimes deposited as concretions around organic remains, pumice fragments and other nuclei, forming manganese nodules of larger or smaller size, especially where the debris, ashes, and lapilli, of basic volcanic rocks are abundant and have

undergone decomposition. These manganese nodules vary in form and size in different localities; at one place they may be large subspherical, and smooth, resembling a lot of potatoes; at another place, smaller, like marbles; at another place large and spherical, but the external surfaces rough to the touch, owing to the numerous mammillations (Fig. 153); at another place flattened with one side rougher than the other; and at yet another place the nodules take the form of huge slabs. With the manganese nodules are usually associated, especially in deep water far from land, numerous teeth of sharks and ear-bones of whales, impregnated and coated more or less thickly by the peroxides of iron and manganese. In the Red Clays, also, numerous minute magnetic spherules (Fig. 154), some with metallic nuclei, have been met with, and have also been extracted from the manganese nodules after these have been broken up in a mortar; these spherules are supposed to have fallen from interstellar space, and are hence called 'cosmic spherules'. In some positions, again, there are small zeolitic crystals (phillipsite), as individuals, twins, stellate groups, and spherulitic aggregations; these are supposed to be secondary products, formed *in situ*, arising from the

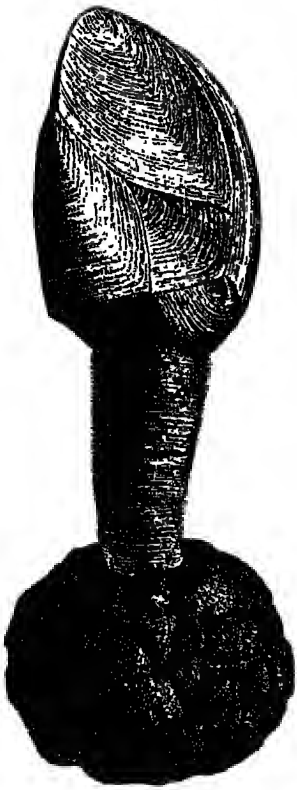


FIG. 153. Scalpellum on a Manganese Nodule

decomposition of the basic volcanic particles present in the deposits.

Red Clay is estimated to cover an area of about 51,500,000 square miles (or 133,975,000 square kilometres)—i.e. about 40,800,000 square miles in the Pacific Ocean, about 5,800,000 square miles in the Atlantic Ocean, and about 4,900,000 square miles in the Indian Ocean.

2. **Radiolarian Ooze.** This deposit is distinguished by the abundance of the skeletons of Radiolaria, and is found typically in very deep water in the tropical regions of the Pacific and Indian Oceans. It is otherwise similar to the Red Clay just described, and may contain a few shells of pelagic Foraminifera and small angular volcanic mineral particles, fragments of pumice, augite, felspars, hornblende, magnetite, volcanic glass, frequently altered into palagonite, as well as manganese nodules, sharks' teeth, and ear-bones of cetaceans.

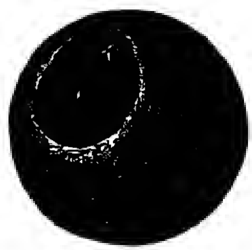


FIG. 154. Spherule with metallic nucleus coated with black Magnetite, supposed to be of cosmic origin

Radiolarian Ooze is estimated to cover an area of about 2,290,000 square miles (or 5,957,000 square kilometres)—i.e. about 1,160,000 square miles in the Pacific Ocean, and about 1,130,000 square miles in the Indian Ocean.[1]

3. **Diatom Ooze.** This deposit is distinguished by the prominence of Diatom frustules (skeletons), and is therefore characteristic of those regions in which these pelagic plants swarm in the surface waters, as in the extreme northern part of the Pacific and far south in the neighbourhood of the Antarctic circle. The skeletons of Radiolaria

[1] A small patch of Radiolarian Ooze has since been found by the *Discovery* Expedition in the South Atlantic at 46° S. 23° W., and 50° S. 30° W.—*Ed.*

and the shells of one or two species of pelagic Foraminifera are usually present, as well as continental mineral particles and ice-borne rock fragments, since this deposit occurs generally within the regions affected by floating ice (Fig. 155).

In some of the Red Clays and Radiolarian Oozes of the Central Pacific the frustules of the large diatom Cos-

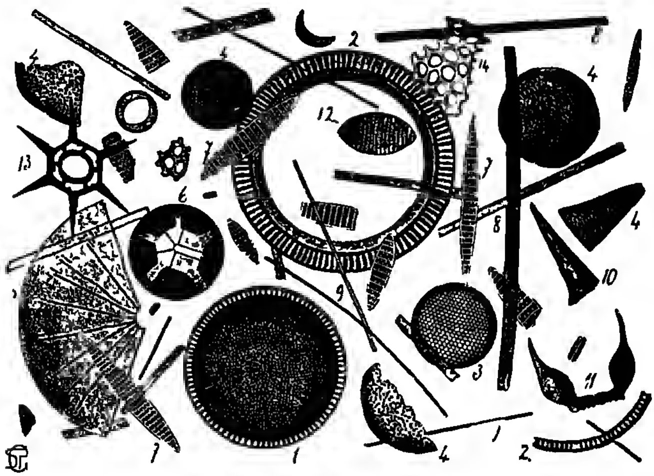


FIG. 155. Diatom Ooze
1–5, Coscinodiscus; 6, Asteromphalus; 7, Fragilaria antarcica; 8, 9, Synedra; 10, Rhizosolenia; 11, Chaetoceras; 12, Navicula (?); 13, Dictyocha; 14, a broken Radiolarian

cinodiscus rex are so abundant that the deposit has sometimes been described as a Diatom Ooze.

Diatom Ooze is estimated to cover an area of about 10,880,000 square miles (or 28,300,000 square kilometres)—principally in the Southern Ocean, with a small area in the North Pacific Ocean.

4. **Globigerina Ooze.** This deposit is named from the predominance of the dead shells of Foraminifera, which lived in the surface waters of the ocean, the genus Globigerina (Figs. 74, 156) being the most characteristic,

though the representatives of other genera are usually present in the tropics (Fig. 157). Associated with the

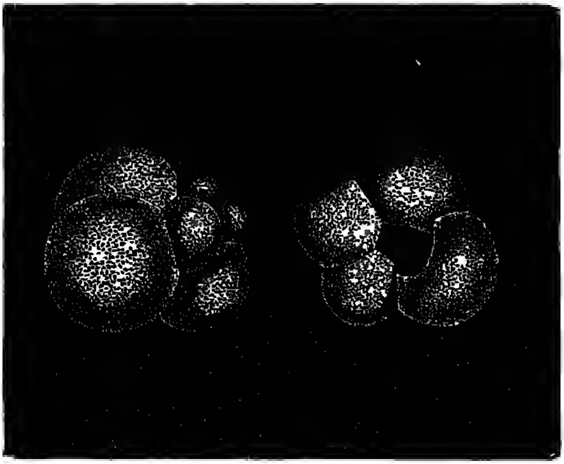


FIG. 156. Dead shells of Globigerina, the spines of which have been dissolved in their fall to the bottom

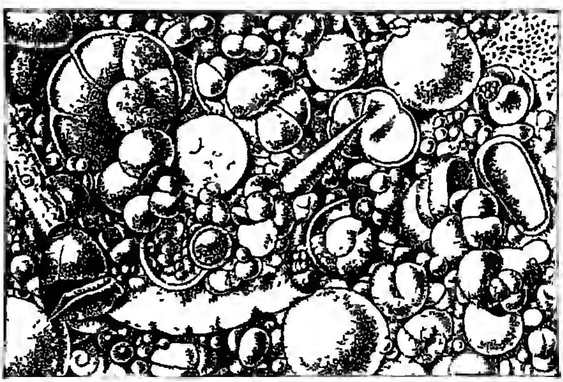


FIG. 157. Globigerina Ooze, consisting largely of Foraminiferan shells

shells of pelagic Foraminifera are the shells of pelagic Molluscs (Pteropods and Heteropods), pelagic calcareous Algae (Coccospheres and Rhabdospheres, or their broken fragments—Coccoliths and Rhabdoliths), as well as the

remains of calcareous organisms, which habitually live on the bottom of the sea, such as Molluscs, Echinoderms, Annelids, Corals, Polyzoa, and bottom-living Foraminifera. The remains of siliceous organisms (Radiolaria, Diatoms, and Sponge spicules) may generally be detected, and a few small mineral particles, such as felspar, augite, hornblende, magnetite, and volcanic glass, with a small quantity of clayey matter coloured by the oxides of iron

FIG 158 Pteropod Ooze, consisting mainly of Pteropod and Foraminiferan shells

and manganese. This deposit varies greatly in composition, both with respect to the species of organisms present and their relative abundance, and also in the abundance and nature of the mineral constituents. In all the great depths of the ocean, exceeding 2,500 or 3,000 fathoms, Globigerina Ooze gives place to Red Clay, even in those regions where pelagic Foraminifera inhabit the surface waters in great profusion; this is ascribed to the longer time during which the shells are exposed to the solvent action of sea-water, while falling through the greater depth of water, and while lying uncovered on the bottom.

Globigerina Ooze is estimated to cover an area of about

49,520,000 square miles (or 128,824,000 square kilometres)—i.e. about 22,500,000 square miles in the Atlantic Ocean, about 14,800,000 square miles in the Pacific Ocean, and about 12,220,000 square miles in the Indian Ocean.

5. **Pteropod Ooze.** This deposit differs from Globigerina Ooze only in the greater abundance of the shells of pelagic Molluscs (Pteropods and Heteropods), and occurs characteristically at lesser depths than the Globigerina Ooze (Fig. 158). Thus Pteropod Ooze may be said to attain its typical development at depths of 800 to 1,000 fathoms, while Globigerina Ooze occurs typically at depths of 1,500 to 2,000 fathoms. The reason why the shells of pelagic Molluscs are removed from the deposits at lesser depths than the shells of pelagic Foraminifera is believed to be that these thin and fragile shells present a larger surface to the solvent action of sea-water.

Pteropod Ooze is estimated to cover an area of about 400,000 square miles (or 1,000,000 square kilometres), principally in the Atlantic Ocean.

B. TERRIGENOUS DEPOSITS

6. **Blue Mud.** This deposit is the one most frequently met with in the deeper waters surrounding continental land and in enclosed and partially enclosed seas. It is principally composed of materials derived from the disintegration of continental land, consisting largely of the fragments and minerals of continental rocks (the older crystalline and schistocrystalline rocks, quartzites, sandstones and limestones) of various dimensions, but usually larger near shore and smaller as the deep sea is approached, except in the regions affected by floating ice. Quartz is the characteristic mineral species, associated with orthoclase and plagioclase felspars, green hornblende, mica,

&c.; glauconite is usually present, but not in such abundance as in the Green Mud. There is usually a considerable proportion of amorphous clayey matter, increasing in amount with increasing distance from land, so that some of the deeper samples have a decidedly clayey aspect, but the deposit, as a rule, may be described as earthy rather than clayey. In some situations the remains of bottom-living organisms may be present in considerable numbers, and in others the remains of pelagic organisms may be so abundant that the deposit resembles a Globigerina Ooze.

Blue Mud is estimated to cover an area of about 14,500,000 square miles (or 37,700,000 square kilometres).

7. **Red Mud.** This is a local variety of Blue Mud, hitherto known only from the Yellow Sea in the Pacific, and off the Brazilian coast in the Atlantic, characterized by the presence of a large quantity of reddish ferruginous matter brought down by the large rivers in the vicinity.

Red Mud is estimated to cover an area of about 100,000 square miles (or 260,000 square kilometres).

8. **Green Mud.** This is a variety of Blue Mud, found along bold exposed coasts where no very large rivers enter the sea, and distinguished by the greater or less abundance of green glauconite grains and glauconitic casts (internal models in green sand), of the shells of calcareous organisms, usually associated with a greenish amorphous (probably organic) matter. In the shallower depths the glauconitic grains and casts are sometimes associated with phosphatic concretions, while the amorphous clayey matter is less abundant, and the deposits, being more granular and more incoherent, are called Green Sands.

Green Mud is estimated to cover an area of about 1,000,000 square miles (or 2,600,000 square kilometres).

9. **Volcanic Mud.** This deposit occurs around oceanic islands and submarine elevations of volcanic origin, and is made up largely of volcanic rock fragments and volcanic mineral particles, such as lapilli of basaltic and andesitic rocks, especially the vitreous varieties, sanidine, plagioclase, augite, hornblende, rhombic pyroxenes, olivine, and magnetite. In shallower waters the volcanic particles are larger, associated with less amorphous clayey matter, and the deposits, being less coherent, are called Volcanic Sands. The remains of floating or bottom-living calcareous organisms may become so abundant that it is sometimes difficult to distinguish this deposit from a Globigerina Ooze on the one hand, or from a Coral Mud or Sand on the other.

Volcanic Mud is estimated to cover an area of about 750,000 square miles (or 1,950,000 square kilometres).

10. **Coral Mud.** This deposit occurs off coral islands and coral reefs, and is chiefly made up of fragments of organisms living in the shallow waters and on the reefs, such as calcareous Algae, Corals, Molluscs, Polyzoa, Annelids, Echinoderms, and Foraminifera. In the shallower waters near the reefs these calcareous fragments are larger, and the more finely divided calcareous matter is less abundant than in the deeper waters further removed from the reefs; the deposits are then called Coral Sands. These deposits may contain, at times, much volcanic material.

Coral Mud is estimated to cover an area of about 2,700,000 square miles (or 7,000,000 square kilometres).

General Remarks

The Black Sea is far removed from the great oceans, and its deeper water is cut off by submarine barriers at the Bosphorus from the Mediterranean, which in its turn is

cut off from the Atlantic by an additional barrier at the Straits of Gibraltar. Vertical circulation is much restricted by this and by the fact that the surface layers are often much less saline than the deeper layers; hence the deeper waters of the Black Sea become more or less saturated with sulphuretted hydrogen; no living organisms (other than bacteria) are met with in depths greater than 100 fathoms. Amorphous carbonate of lime is precipitated from the water of the Black Sea, and makes up a considerable part of the deposits now in process of formation; this is the only place where this is known to occur in the seas of the present day. In all partially enclosed seas—like the Mediterranean and the Red Sea—circulation is generally cut off by submarine barriers, and this results in thermal and other conditions which are less favourable to organisms than the conditions existing in the open ocean. The deposits in those seas which interpenetrate the continental masses are terrigenous in origin, although there may be an approach to pelagic conditions towards the more central parts.

It has already been observed that the continental shelf facing the great oceans is continually swept by waves, tides, and oceanic currents, down to an average depth of 100 fathoms. Just beyond this depth all the minute mineral and organic fragments from the continental shelf come to rest on the bottom, and form what I have called the 'mud line'. This constitutes the great feeding-ground of the ocean. Large numbers of Holothurians and other marine creatures here eat the mud to obtain the organic matter associated with it. Indeed, it is more than probable that all marine deposits are in this way passed through the intestines of organisms. Very many Crustaceans frequent this area to pick up the little particles of organic matter which are just settling on the bottom, and some of them—

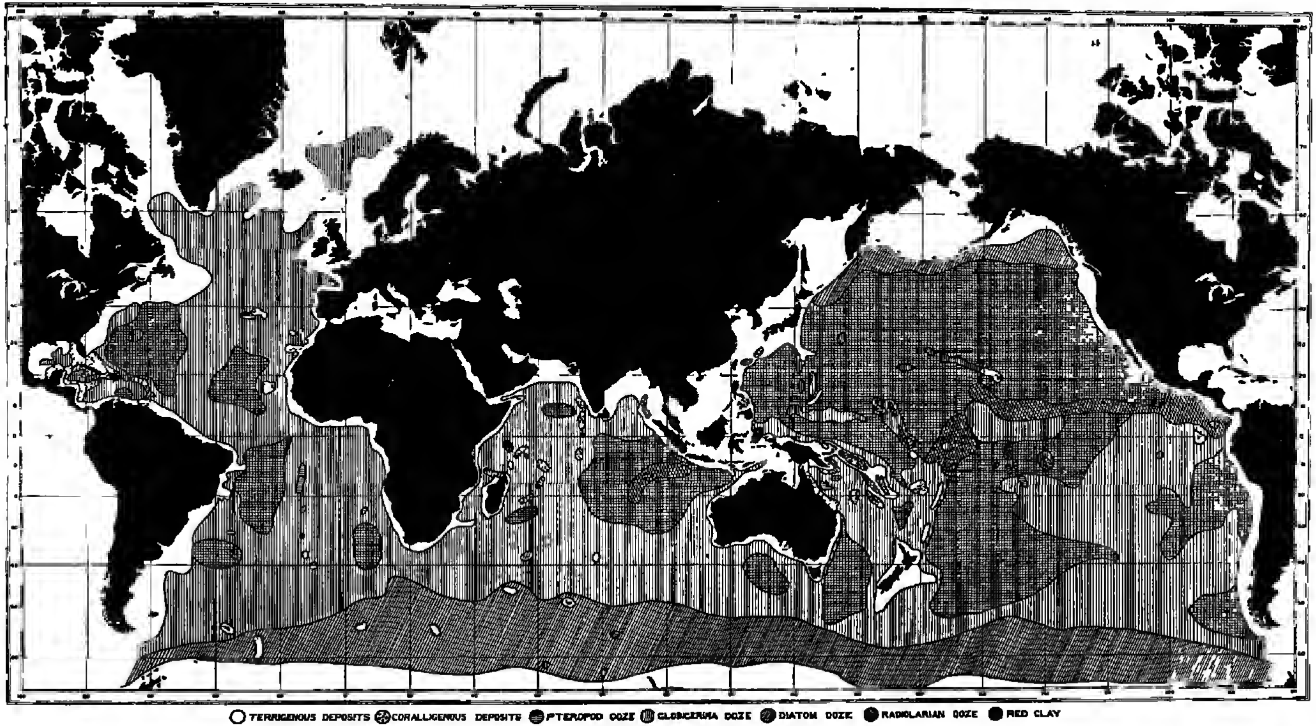


CHART X.—BOTTOM DEPOSITS

Only the larger areas are here shown

like Nyctiphanes—are provided with phosphorescent organs to enable them to do this more effectively. All these mud-eating creatures are in turn the prey of carnivorous animals, both vertebrate and invertebrate.

The continental slope extends from the mud line (100 fathoms) down to the mean sphere level (1,450 fathoms).[1] The continental slope and similar areas around oceanic islands present a greater variety of conditions than is found elsewhere on the ocean bed. At the upper limit the sun's rays may produce twilight, but elsewhere there must be total darkness, except where this is relieved by the phosphorescent light of organisms. The temperature conditions are likewise widely different at the upper and lower limits of the region. At some points the descent from the 100-fathom line is known to be almost perpendicular; at other points outcrops of stratified and volcanic rocks are indicated.

The deposits now being laid down over the continental slope vary greatly according to position. Off large rivers they are chiefly made up of detritus from the land; at other places, especially where cold and warm currents alternately occupy the surface, pelagic conditions are more or less pronounced, and greensand and phosphatic deposits are being laid down; quartz and other continental minerals predominate. Generally it may be said that in enclosed seas, and along the continental shelf and slope, deposits are being formed quite similar to those which have made up the stratified rocks of past ages. Indeed, it seems as if inland seas and the borders of continental masses had again and again been pushed up into dry land, and again and again been torn down and transported to the ocean

[1] If all the elevated portions of the earth's crust were cut away, and filled into the hollows till the whole surface was uniform, then the whole earth would be covered by an ocean 1,450 fathoms in depth—the mean sphere level.

by the same denuding and disintegrating agents, the final result being that quartz particles accumulate on the continental areas, rendering these rocks specifically lighter than the deposits on the oceanic areas.

In the abyssal regions, beyond the depth of the mean sphere level covering about one-half of the earth's surface, the physical conditions are uniform and widespread; the temperature everywhere approaches zero Centigrade; the darkness is relieved only by phosphorescent light; motion of all kinds must be extremely slow, and there is little evidence of transport or erosion. In these cold and silent depths the deposits vary accordingly to the surface conditions; where organisms which secrete carbonate of lime abound at the surface, we find Globigerina or Pteropod Oozes at the bottom; where silica-secreting organisms abound at the surface we find Radiolarian or Diatom Oozes at the bottom. In very great depths the calcareous organisms are removed by solution, and in some places the siliceous skeletons are also partly removed. From the deep water of the South Pacific Ocean, at points the farthest removed from continental land on the globe, the trawl brings up over wide areas hundreds of sharks' teeth and dozens of ear-bones of whales, some of them belonging to extinct species, tons of manganese nodules and, mixed up in the clay, magnetic spherules of metallic iron and nickel, and chondres, which are only found in meteorites. All the indications go to show that the rate of accumulation of the deposit is extremely slow, possibly not more than a foot since Tertiary times. The reason why these teeth and bones and extra-terrestrial spherules are found here more abundantly than elsewhere is because few other materials reach these remote and deep areas to cover up or mask them, as in other deposits.

Throughout the abyssal area quartz fragments, when

present, are rare, when compared with their abundance in the terrigenous deposits close to shore, and it is very doubtful if any stratified rock has yet been discovered which can be regarded as the equivalent of any deposit now forming in the deep water far from continental land. It is extremely difficult to imagine how a continent, as we understand the term, could ever have existed in the centre of any of the great ocean basins, which appear to be the most stable portions of the earth's crust, while the continental areas, especially the border regions, are the most unstable.

From a recent examination of some *Challenger* deposits sent to him from the *Challenger* Office, Professor J. Joly has been able to give the radium contents of deep-sea deposits. He finds that the Red Clays and Radiolarian Oozes contain much more radium than the Globigerina Oozes or terrigenous deposits; in fact, the radium content is greatest where the rate of deposition is believed to be the least. The idea at once suggests itself that this is connected with the greater amount of cosmic dust in the deep deposits far from land. This is well worthy of the attention of those who in future may dredge up large samples of deposits from the Red Clay areas.

VII

ANIMALS OF THE SEA FLOOR

BY G. P. FARRAN AND W. T. CALMAN

In dealing with the fauna of the sea bottom it is necessary to make use of some convenient and natural classification of the subject. It has long been recognized that, in passing from the shallow water surrounding the shore to the abysses of the ocean, we may find many striking changes in the character of the inhabitants associated with the increasing depth; and a classification based on the depth at which the animals live is a more or less natural one. While those areas or zones of depth which are accepted are marked out, rather on account of their physical features than because they possess separate faunas sharply defined from each other, still the assemblage of animals found in each zone, taken as a whole, differs considerably from those of the other zones, and may conveniently be dealt with apart from them.

The zones of depth usually distinguished in European seas are based on those originally defined by Edward Forbes in the middle of the last century. These were the Littoral Zone, the Laminarian Zone, the Coralline Zone, and the region of Deep-Sea Corals. For the last two may be substituted the Continental Shelf and the Continental Slope, and to the list may be added the ocean floor, a region which in Forbes's day was believed to be devoid of living inhabitants, but which more recent research has proved to have a varied fauna. These zones must be taken as applying primarily to the shores of the North Atlantic and the Mediterranean, but with some small alteration will be found to hold good for many other seas.

The Littoral Zone, or the space between high and

low-water mark, is dealt with elsewhere in this volume (Chapter III). It is necessarily inhabited by a fauna which is able to endure a certain amount of periodic exposure to the air. At its lower limit it passes into what is known in European waters as the Laminarian Zone, taking its name from the oarweed or Tangle (Laminaria), which, with other seaweeds, is its most striking feature. It extends to a variable depth, usually less than 15 fathoms. Though the name Laminarian is somewhat restricted in its application, yet the physical characters of this zone may be recognized almost universally. These may be summed up as the penetration of sunlight, and the consequent presence of abundant vegetable life in the form of brown and red seaweeds; the exposure to violent wave action which may stir up sediment, and the lowered salinity from the surface drainage of the land, even in the absence of any large rivers. It is in this zone that we must look for the majority of the vegetable feeders of the sea, with the exception of those which live upon minute floating diatoms and similar organisms of the plankton.

Below the region in which the brown seaweeds flourish, or (speaking very roughly) from 15 fathoms downwards, lies the region which we now deal with comprehensively as the Continental Shelf.

As a general rule the land-masses of the globe are surrounded by an area of comparatively shallow water, varying in extent, which has been called the 'area of the Continental Shelf'. This shelf or margin, sloping gradually to a depth of 100 or 200 fathoms, and extending for a distance of from 20 to 200 miles from the shore, is succeeded by a relatively steep declivity, the Continental Slope descending to the ocean floor; this latter then stretches, at a depth of between 1,000 and 3,000 fathoms, over an area measuring about one-third of the whole

surface of the globe, and is hollowed out in places into depths of 4,000 or even 5,000 fathoms (cf. Chapter VI). The edge of the Continental Shelf may be taken as a dividing line between two faunal areas, the sloping descent of a continent to the ocean floor being regarded as a sort of neutral ground which, while having a few inhabitants that belong more properly to the Continental Shelf and a few peculiar to itself, is for the most part peopled by species which may be regarded as belonging to the fauna of the deep sea.

It is to be remembered that this dividing line does not mark any sudden change either in the physical conditions or in the animals to be met with, and that any limit which may be chosen must in the nature of things be more or less an arbitrary one, and its position will be different in different regions.

The physical conditions prevailing over the sea bottom are dealt with fully in other parts of this volume (Chapters II and VI), and it is only necessary to call attention to some of the chief differences between the areas which we are considering.

The Laminarian Zone and Continental Shelf

Throughout the area extending from low-water mark to the edge of the Continental Shelf we find that the variability and liability to sudden alterations in physical conditions, which are so noticeable in the shallow water, become very much reduced. The changes in temperature in the deeper parts of the area are rather seasonal and gradual than diurnal or rapid, and are not dependent immediately on the alterations of the temperature of the air. The mean temperatures in various regions show, of course, very great differences.

The salinity, like the temperature, is locally fairly constant, the changes being slow, and the range comparatively small, though great differences may be noticed between different seas. The light is very much diminished, passing from a dim twilight in the more shallow parts to complete darkness in the deeper. The actual depth to which light can penetrate depends very much on the clearness of the water and its freedom from sediment; but it may be taken that at depths exceeding 600 fathoms practically no light can be received from above, while at depths considerably less the amount of light is so small as to have little influence on life.

The absence of light entails the absence of plant life and consequently of vegetable feeders, with the exception of such forms as subsist on microscopic floating vegetable matter. The greater part of the area is too deep to be troubled by wave action, and the force of tides and currents is much diminished. The bottom is fairly uniform over large areas, though the actual types of bottom do not differ materially from those found immediately adjoining the shore, the materials of the sea floor in both cases being derived from the debris of the adjacent land. It is usually the case that the composition of the bottom becomes finer as the depth and the distance from shore increase, but this is by no means a universal rule, gravel, rocks, and stones being often met with even beyond the edge of the Continental Shelf. The water overlying this zone contains in suspension a quantity of organic and mineral matter derived from the shore. The importance as a food supply of finely divided organic matter of vegetable origin, or 'detritus' as it is generally called, appears to be greater than was at one time suspected. Many mollusca and other bottom-living animals seem to use it in shallow land-locked waters, where the breaking up by wave action of

each year's summer growth of seaweed and zostera furnishes an abundant and perennial supply. This detritus may drift out with the currents to considerable distances from the shore; at what point it ceases to be a factor in the food-supply of the bottom-living animals it is difficult to determine. Murray indicated a limit, which he called the 'mud-line', at just beyond the 100 fathom line, and considered the area included by it as 'the great feeding-ground of the ocean'.

Taken as a whole, the area from low-water mark to the edge of the Continental Shelf possesses a fauna which is perhaps richer and more varied than that of any other area on the surface of the globe. A catalogue of its inhabitants would include all the chief types of invertebrate animals (except the air-breathing Arthropods) and many fishes. It would be impossible within the space at our disposal to attempt even an outline sketch of this fauna and of its variations in different parts of the world, but for the guidance of those unfamiliar with zoology a few of the commoner types represented in the illustrations may be mentioned.

The simplest animals (Protozoa) are represented especially by the bottom-living Foraminifera, which are abundant in certain localities, creeping on the surface of the mud or firmly adhering to stones or other solid bodies. The shells of the Foraminifera are often exceedingly beautiful (Figs. 159–63). They are generally composed of carbonate of lime, but some are built up of grains of sand cemented together. Most of them are of microscopic size, although in tropical seas some species may be as much as an inch across, and even in the cold waters of the deep Norwegian fjords the star-shaped sandy Astrorhiza is as big as a threepenny piece (Fig. 162).

Sponges (Porifera) often form a conspicuous part of the

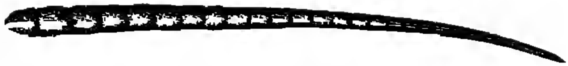


Fig. 159. Nodosaria

Fig. 160. Spiroloculina

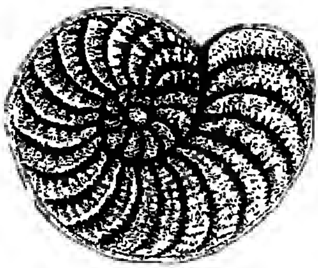


Fig. 161. Polystomella

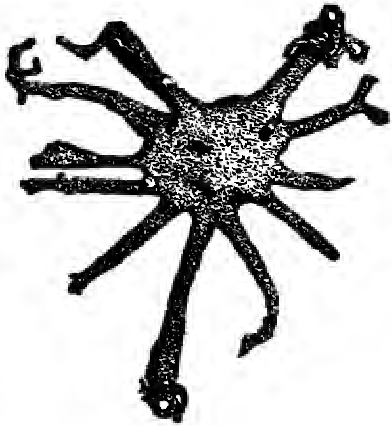


Fig. 162. Astrorhiza

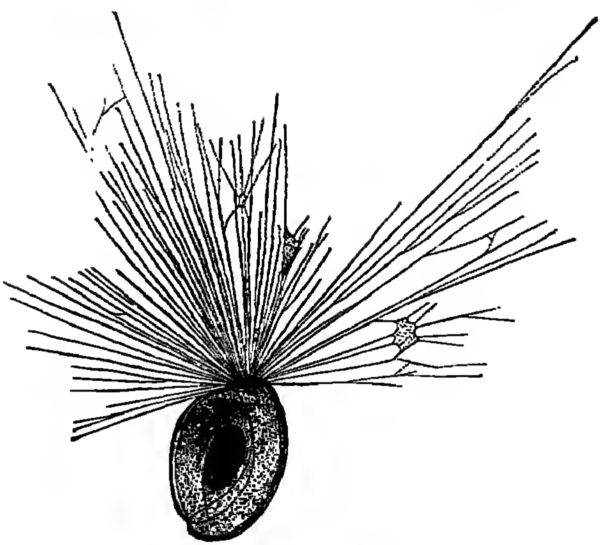


Fig. 163. Miliolina

TYPES OF FORAMINIFERA

contents of the dredge or trawl in waters of moderate depth, and deserve the attention of the collector, not only for their own sake, but also on account of the numerous Crustacea, worms, and other animals which burrow in them or shelter in the crevices. In passing from shallow to deeper water the shapeless encrusting sponges of the littoral region are replaced, in part at least, by types of definite and often beautiful form (Fig. 164). This is especially the case with the glass-sponges (Hexactinellida), of which the well-known Venus's Flower-basket is an example.

Below the depth at which true seaweeds flourish the dredge is often filled with masses of what the fisherman or trawler terms 'weed', but which the zoologist recognizes as plant-like animals. Even for the zoologist it is not always easy to distinguish by the unaided eye between the feathery tufts of Hydroids (Figs. 87, 89, 165) and the much more highly organized Polyzoa. Belonging to the same division of the animal kingdom (Coelenterata) as the Hydroids are the sea-pens, or Pennatulida (Fig. 166), the sea-fans, or Gorgoniacea (Figs. 167, 168), the fleshy masses of the 'dead-men's-fingers' (Alcyonaria), the red or precious coral (Corallium), the sea anemones, and the true corals (Madreporaria), both colonial and solitary (Fig. 169); the true corals are by no means confined to the warmer seas, although it is only there that they display their full luxuriance.

Starfishes (Fig. 171), brittle-stars (Fig. 170), sea-urchins (Fig. 173), and their kindred are abundant in all seas. Belonging to the same group (Echinodermata) are the sea-cucumbers, trepangs, or Holothuroidea (Fig. 176), and the feather-stars (Crinoidea), some of the latter free-living like the Antedon of our own seas, some attached by a stalk like the 'stone-lilies' of earlier geological epochs

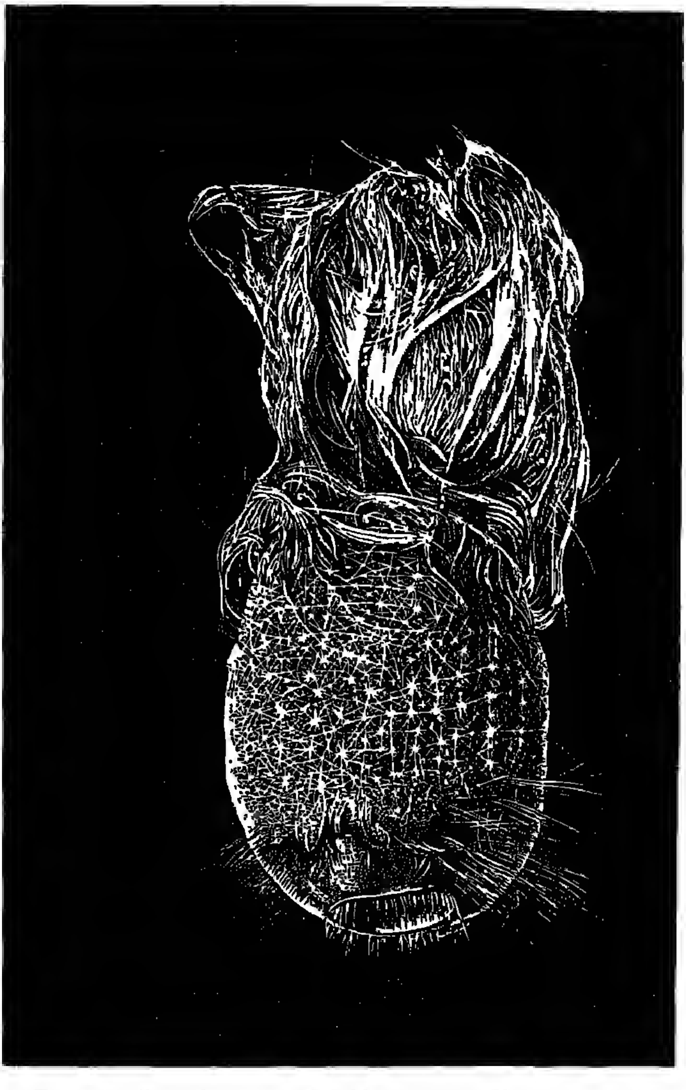


FIG. 164. Holtenia, a Deep-Sea Glass Sponge (*Challenger*). ⅟ ½

(Fig. 177). Thcsc stalked crinoids, confined for the most part to fairly deep water, were formerly among the most prized rarities of zoological collections, though the progress of deep-sea exploration has now rendered them tolerably familiar.

Under the name of 'worms' are included very many animals of widely dissimilar appearance. The Planarians are mostly flattened leaf-like forms, often of brilliant colours, which glide smoothly over the surface of stones or shells. The Nemertines may be recognized by their soft, very extensile bodies, and their long thread-like proboscis, which can be completely withdrawn within the animal. They are frequently richly coloured and of very varied form, some slender and of immense length, others short and thick and very fragile, breaking up into small fragments on the least provocation. Burrowing in mud or clay we find the Echiuroids, or spoon-worms, and the Sipunculoids, the latter with tough leathery bodies, blunt at the tail, and tapering to a small proboscis, which can be withdrawn into the body like the finger of a glove which is turned inside out.

By far the most important and numerous group of worms is that of the bristle-worms, or Polychaetes, which are to be found practically everywhere in salt water (Figs. 172 and 174). They carry stumpy, foot-like lobes beset with bristles along each side of the body, by means of which they crawl or swim, and breathe by gills which are either situated on the lateral lobes, or else (in the tube-dwelling forms) crowded on the head of the animal. These Polychaetes may be found in most unexpected places, one species living in the topmost coils of a dead shell inhabited by a hermit-crab, another in the groove on the underside of the common sandstar, and yet another clinging closely to the underside of a species of sea-cucumber.

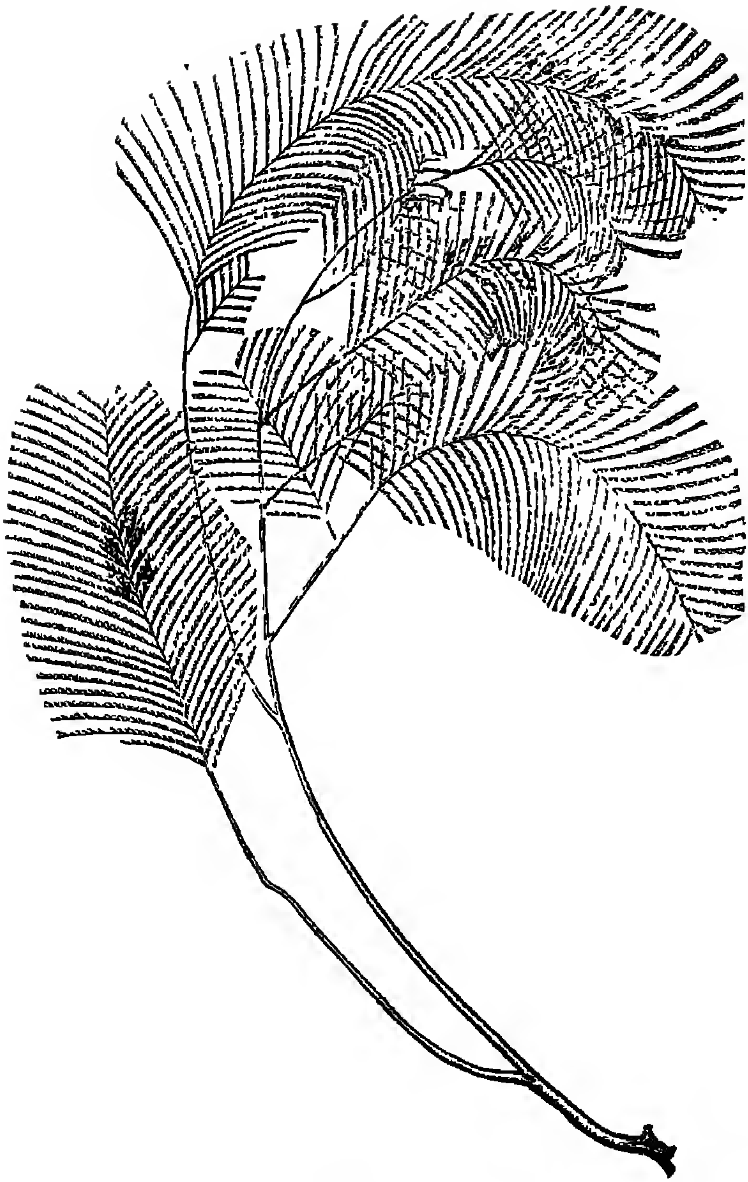


FIG 165. Cladocarpus, a Hydroid. $\times \frac{1}{2}$

The tube-building forms display an endless variety in their habitations. The tough parchment-like tubes of Chaetopterus and Hyalinoecia (Fig. 174) are buried in sand or mud, others are made of sand or broken shells, some roughly put together, and some built up with exquisite neatness and symmetry. Many species secrete calcareous tubes of various shapes, usually fastened to stones or shells, and closed by a stopper which the inhabitant carries attached to his head. The feathery plumes which many of these tube-dwellers bear as gills are among the most attractive sights of an aquarium, where alone they can be seen to full advantage (Fig. 172). Perhaps the most graceful are those of Sabella and its allies, whose tubes, built largely of mud, have the appearance and texture of india-rubber piping. Though most of the free-living Polychaetes are unable to swim, there are a few entirely pelagic species; and some of the normally creeping forms, when the breeding season arrives, become entirely altered in appearance, developing swimming-lobes along the sides of their bodies, and come to the surface in immense swarms. The 'Palolo' of Pacific islands, which, leaving its shelter in the coral reefs, suddenly appears in countless numbers on the shore, is a well-known instance of this change of habit.

The huge group of the Crustacea is one which perhaps attracts more attention than any other. In number of species it far exceeds any other group of marine animals, but most of these are of very minute size. It is perhaps not out of place to suggest here that, in order to capture these smaller forms, the water in which dredged material has been put to stand should be strained off through a piece of fine silk. Very unlike the other Crustacea in appearance are the Cirripedes, including both the stalked barnacles and the sessile acorn-

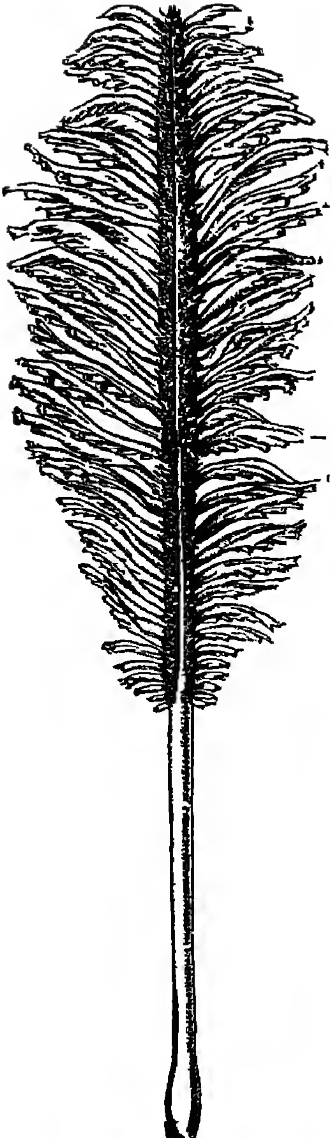


Fig 166 Pennatula, a Sea Pen × $\frac{3}{4}$

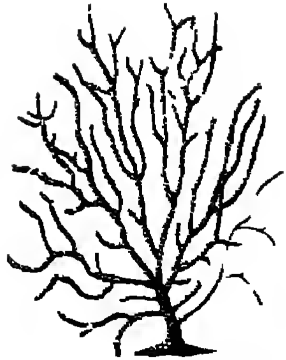


Fig 167 Gorgonia a Sea Fan Reduced

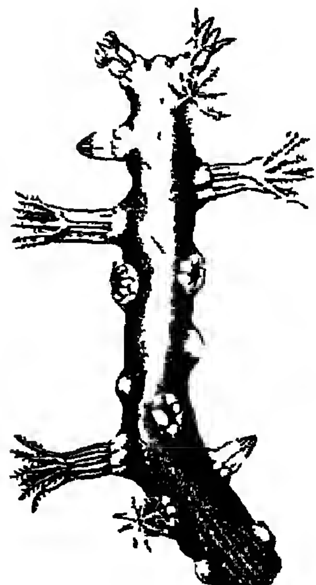


Fig 168 Gorgonia, showing the Polyps in Contraction and Expansion Enlarged

shells. The stalked forms are often found growing on floating objects, but some genera such as Scalpellum are found in deep water attached to Hydroids or other fixed objects (Fig. 153, p. 258). The sessile or acorn-barnacles are most abundant between tide-marks or in shallow water, but there are a few deep-sea species. Of the other Crustacea, the Branchiopods belong to the plankton (Chapter V), but the Copepods and Ostracods have many bottom representatives.

There are two very large groups of Crustacea, numbering some thousands of species, which we may conveniently illustrate by the sandhopper and the wood-louse. These are the Amphipods (Fig. 179) and the Isopods (Fig. 182). They may be found everywhere, and may, for the most part, be recognized by their resemblance to the types above mentioned. One section of the Amphipods, however, the ghost shrimps, or Caprellids, differs very markedly from the rest. The Caprellids may be recognized by their slender skeleton-like bodies, their thin legs, the two front pairs of which are armed with strong claws, and their 'looper'-like movements (Fig. 180).

The Cumacea, another group of small Crustacea, living for the most part buried in mud, may be known by their small nut-shaped bodies and their long slender tails ending in a fork.

Resembling the Prawns in appearance are the so-called 'Schizopods', a name sometimes used to include two unrelated groups. Of these, the Euphausiacea (Fig. 116, p. 223), are almost entirely pelagic, but the Mysidacea are for the most part bottom-haunting forms, rarely more than an inch in length.

Of the larger Crustacea the most unfamiliar are probably the squills, or mantis shrimps (Squilla) (Fig. 126, p. 225), with small bodies and broad, flattened tails. They

carry a powerful pair of claws, which they lift in a manner that recalls the mantis insect. They are rarely found except in the warmer seas.

The most highly organized, and the largest of the

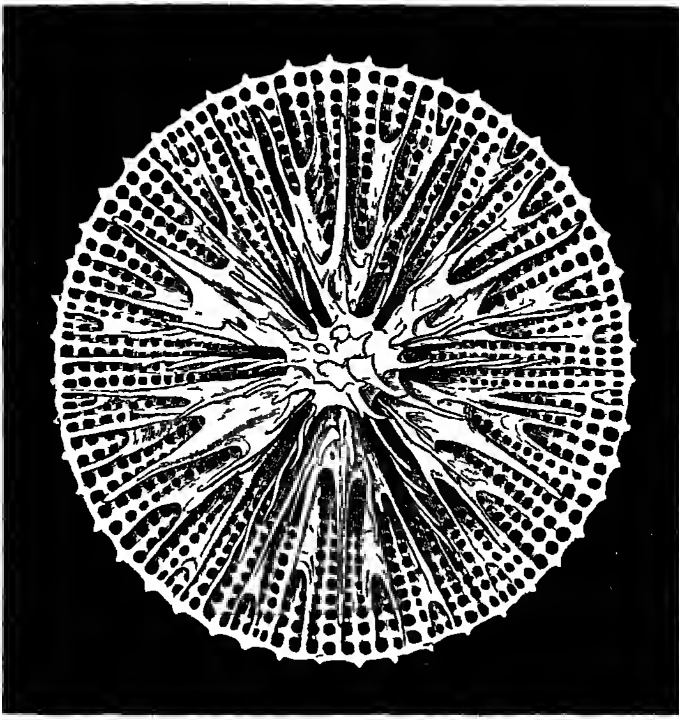


FIG 169 Leptopenus, a Deep-Sea Coral (*Challenger*) × 4

Crustacea, the Decapoda, are usually divided into three groups: (1) the Macrura (or long-tailed), including the lobsters, prawns, and shrimps (Fig. 178); (2) the Anomura (or irregular-tailed)—these comprise, among others, the hermits (Paguridae), with soft bodies (Fig. 181), and the Galatheids, in which the tail is broad and flattened, and can either be turned up under the body or else straightened

out and used for swimming (Fig. 184); (3) the Brachyura, or crabs proper—these include an immense number of very different forms; they retain, however, a sufficient family resemblance for recognition as crabs. Some of the more conspicuous types are the swimming crabs, in which the last pair of legs are paddle-shaped and the body flattened, as in the British genera Portunus and Bathynectes; and the spider crabs, which have the legs long and slender, and apparently more designed for concealment than locomotion, the movements of these crabs being deliberate and sluggish, and their bodies often furnished with a crop of seaweeds, Hydroids, or sponges. The Ebalias, with their small round bodies and closely tucked-in claws, might easily pass for pebbles, and usually frequent ground where the bottom is of coarse gravel.

The sea spiders, or Pycnogonida, are easily recognized by their resemblance to the animals from which they take their English name. In most species the small body scarcely affords room for the attachment of eight (very rarely ten) long slender legs, but in a few cases the legs are short and stout; as, for instance, in the common Pycnogonum littorale, which, in spite of its name, is often found in moderately deep water. Most of the Pycnogons are of small or moderate size, but in some deep-water species the legs may span a length of 2 feet.

The commoner forms of the Mollusca, at any rate of the shelled species, are familiar to every one, but there are some shell-less species, and others with peculiar shells, which call for special note. The usual type of Gastropod, as exemplified by the whelk or periwinkle, bears an asymmetrically coiled shell, but there is reason to believe that the earliest forms of molluscs were symmetrical. This symmetry is still found in the Chitons, in which the shell

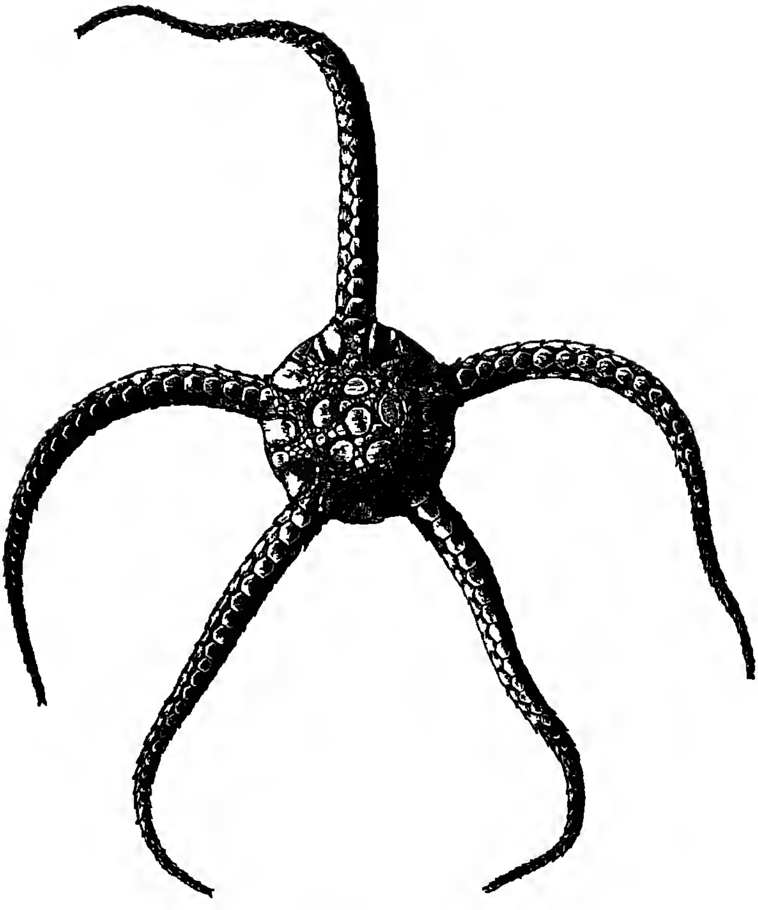


Fig. 170. Ophiura, a Brittle-Star (*Challenger*). × 3

is made up of eight plates, overlapping as in an armadillo or wood-louse (Fig. 185). Allied to the Chitons is a very remarkable group of molluscs, in which the shell is entirely absent. These are for the most part worm-like in form, and are usually found tightly coiled round the branches of Hydroids and Alcyonarians.

The nudibranchs, or sea-slugs, are shell-less gastropods, which externally appear to be symmetrical. They start life, however, in a minute coiled shell. One section of them, the Dorididae, in which the gills are arranged in a circle on the hinder end of the animal, are found in their greatest development, both in number and size, in tropical seas, where, both along the shore and in shallow water, they attract attention by their large size and brilliant colours. Another section, the Eolididae, in which the gills are not concentrated on one spot, but scattered as papillae all over the body, are, on the contrary, very poorly represented in warm seas, but are richly present on our own coasts (Fig. 183).

The Lamellibranchs, comprising such molluscs as the oysters, mussels, cockles, scallops, and so forth, are too well known to need further mention.

Among the Cephalopods, the Octopus and its allies (Fig. 186), with eight equal arms and a rounded body, must be distinguished from the squids and cuttle-fish, which have ten arms, one pair of arms being much longer than the rest. The 'paper Nautilus' belongs to the first of these groups. The second includes a great variety of forms—some short and squat, like the cuttle-fish (Sepia, Sepiola), others elongate, like Loligo and the other squids (Fig. 187). The pearly Nautilus belongs to a group apart from all the rest. It is the sole representative of a once very abundant Order, to which the Ammonites, so well known as fossils, also belonged. Most of the Cephalopods

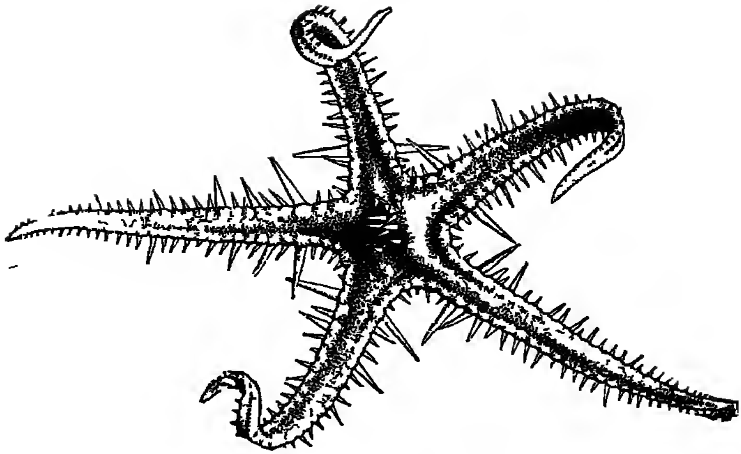


FIG 171 Archaster, a Star Fish Natural size

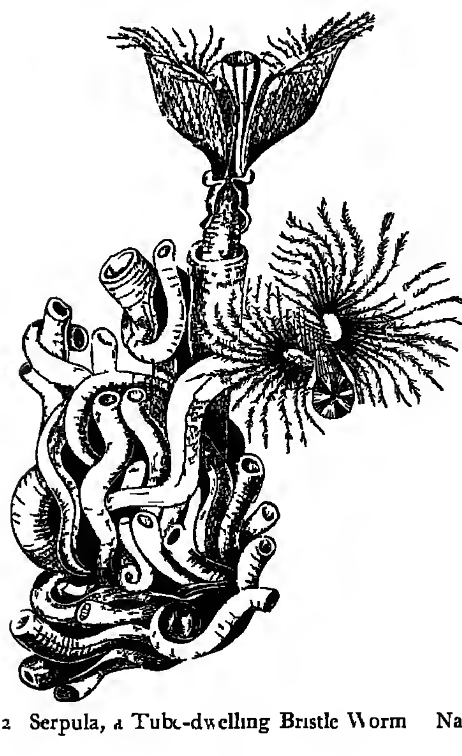


FIG 172 Serpula, a Tube-dwelling Bristle Worm Natural size

can swim very well, and some are entirely pelagic, but most are to be found at the bottom at moderate depths, and some abyssal forms have been found so deep as 2,000 fathoms.

If we look at the stones brought up by the dredge, we are sure to find many of them covered with a fine lace-like incrustation, which, upon close examination, seems to be made up of minute cells, each perforated by a small pore. These cells are formed by the Polyzoa, each cell having a separate inhabitant, which extrudes a tiny crown of tentacles through the opening. Besides the encrusting forms there are other branching ones (Figs. 188, 189), either soft and finely divided, like Hydroids, as already mentioned, or else thick and hard, like small corals.

Allied to the Polyzoa, but differing from them entirely in appearance, is the group known as the Brachiopods, or lamp shells. The Brachiopods were once classed as Mollusca, on account of their external resemblance to Lamellibranchs, but may generally be distinguished from them by the facts that their valves are unequal in size, and that they are attached by a small stalk, which passes out through a hole in the apex of the larger valve (Fig. 185a). They represent a group which was very abundant in early geological times, and of which some forms have persisted almost unchanged to the present day. Many of the species are found at considerable depths.

The Tunicates, or sea squirts, are generally particularly unattractive objects when found among the contents of the dredge. The solitary forms have shapeless sack-like bodies of a gelatinous or leathery texture, often encrusted with mud or sand, and having two openings through which, in the living animal, currents of water enter and leave the body; the colonial forms often encrust stones in large sheets. They are strangely degenerate animals, for

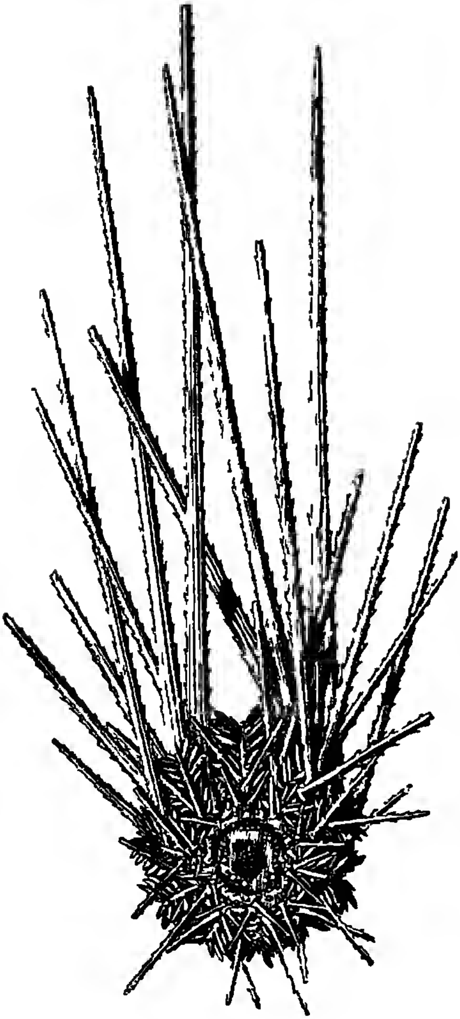


FIG 173

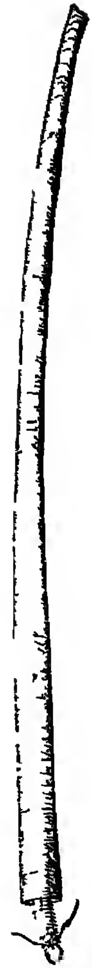


FIG 174

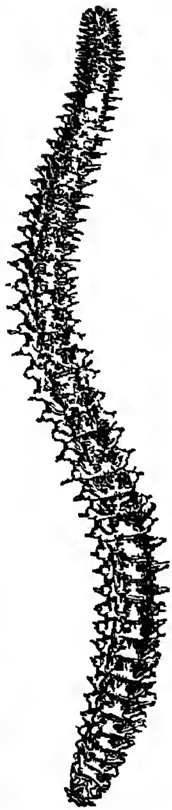


FIG 175

FIG 173 Salenia, a Sea Urchin $\times 4$

FIG 174 Hyalinoecia a Bristle-Worm Reduced

FIG 175 Amphinome, a Bristle-Worm $\times \frac{3}{4}$

they begin life as free-swimming, tadpole-like larvae, which approach somewhat to the Vertebrates in their structure.

As regards the geographical distribution of the animals inhabiting moderate depths, it may be said, speaking very generally, that the character of the fauna is determined rather by temperature than by geographical position. Thus it is found that genera and even species of animals, which may be dredged at a depth of a few fathoms in the Arctic regions, occur at greater depths in the more southern parts of their range, where the shallow water is too warm for them. For example, a certain starfish, which is found commonly off the west coast of Ireland, between 300 and 400 fathoms, and which stretches as far south as the Bay of Biscay in deep water, occurs at a depth of 15 fathoms within the Arctic circle. Again, the current of relatively cold water, which runs northwards along the west coast of South America, allows many of the southern types to extend far to the north, and carries the characteristically subantarctic Isopod genus Serolis to the coasts of Southern California.

It is possible to divide up the shallow water of the globe into regions whose faunae differ from each other, both in the actual species which compose them, and also in the general proportion in which the various groups of the animal kingdom are represented. Thus it is found that the fauna of the shores of East Africa has a much closer resemblance to that of India and of the Pacific than it has to that of South or of West Africa. Similarly, the fauna of the north-east coast of the United States has more species in common with that of the western shores of Europe than with that of the West Indies. Ortmann, in his 'Grundzüge der Marinen Tiergeographie', divided the coastal waters of the globe, down to 100 fathoms, into a

FIG. 176. A Sea-Cucumber or Trepang carrying young ones on its back. Natural size

number of faunistic regions which may be briefly mentioned here.

1. The **Arctic Region**, again subdivided into:
   a. A **Circumpolar** subregion, which includes Greenland, the north coast of Europe and Asia, and the north and north-east coasts of America;
   b. An **Atlantic Boreal** subregion, which includes the west coast of Europe; and
   c. A **Pacific Boreal** subregion, which includes the northern shores of the Pacific Ocean from Japan to California.

The tropical parts of the globe are divided into four regions:

2. The **Indo-Pacific Region**, a very large area stretching from the east coast of Africa to the Islands of Oceania, and including the shores of India, the East Indies, China, and most of Australia.

3. The **West American Region**, which only includes the small stretch of coast line from California to the south of Ecuador.

4. The **East American Region**, from Newfoundland to Cape Hatteras in the United States.

5. The **West African Region**, which is subdivided into
   a. A **Mediterranean** subregion; and
   b. A **Guinea** subregion.

The whole of the Antarctic is included in a single region:

6. The **Antarctic Region**, which includes the south coast of Australia, the coasts of Cape Colony and German South-West Africa, and the greater part of South America, from the River Plate on the east to Ecuador on the west (this northern extension of the cold region being caused, as has been alluded to above, by the current of cold water running up the west coast of South America).

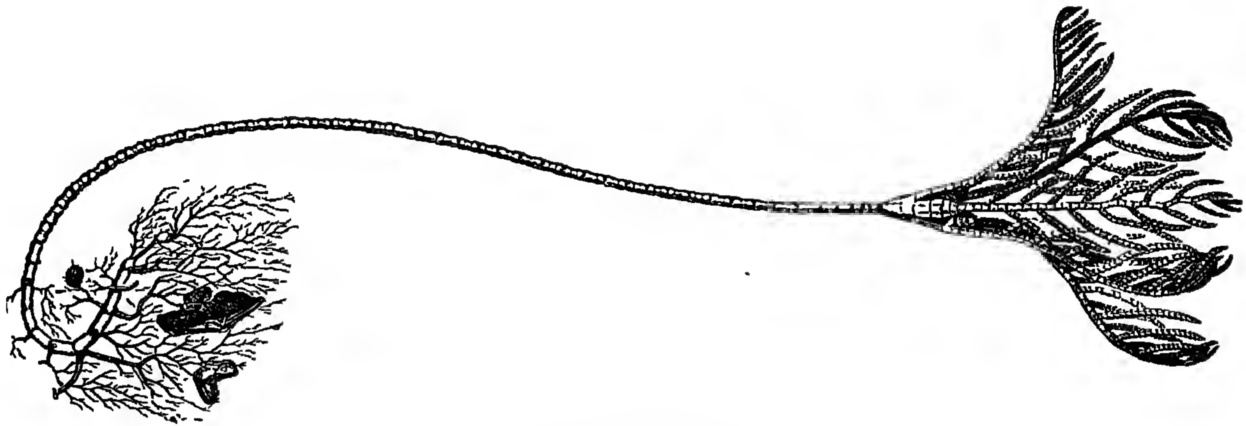


FIG. 177. Rhizocrinus, a Feather-Star. × 1·5

The definition of these regions must not be taken as implying that there is any strict demarcation between their faunae. There is naturally a great deal of overlapping, and very many species are common to two or more regions; for example, a large number of the common marine animals of the British Isles are to be found in the Mediterranean, often at increased depths.

A more detailed subdivision of the seas, on much the same lines as that of Ortmann, but including oceanic bottom areas, and suitable also for planktonic areas, has been adopted by the Challenger Society for bibliographical work, and is reprinted here as Chart XI (p. 304).

The doctrine of 'bipolarity' (that the arctic and antarctic faunae are more closely allied to each other than they are to the inhabitants of the more equatorial waters) is based on the fact that identical or closely allied forms have been found in both north and south Polar seas, but have not been reported from the intervening waters. The number of undoubted cases of this is not large, and most of them may perhaps be explained as being instances of species which belong to a widespread deep-water fauna, which have been taken at the Poles at moderate depths, but have escaped notice in the abysses of the warmer regions where our knowledge of the deep-sea fauna is very limited.

The local distribution of the fauna within the narrower limits of each region appears to depend largely on the varying character of the sea bottom. Within the limits of the zone which we are considering (from the lower limit of the Laminarian Zone to the edge of the Continental Shelf) it may be said that the differences of fauna due to depth are insignificant as compared with those associated with the different kinds of bottom, and therefore it is impossible to attach importance to the subdivisions of this

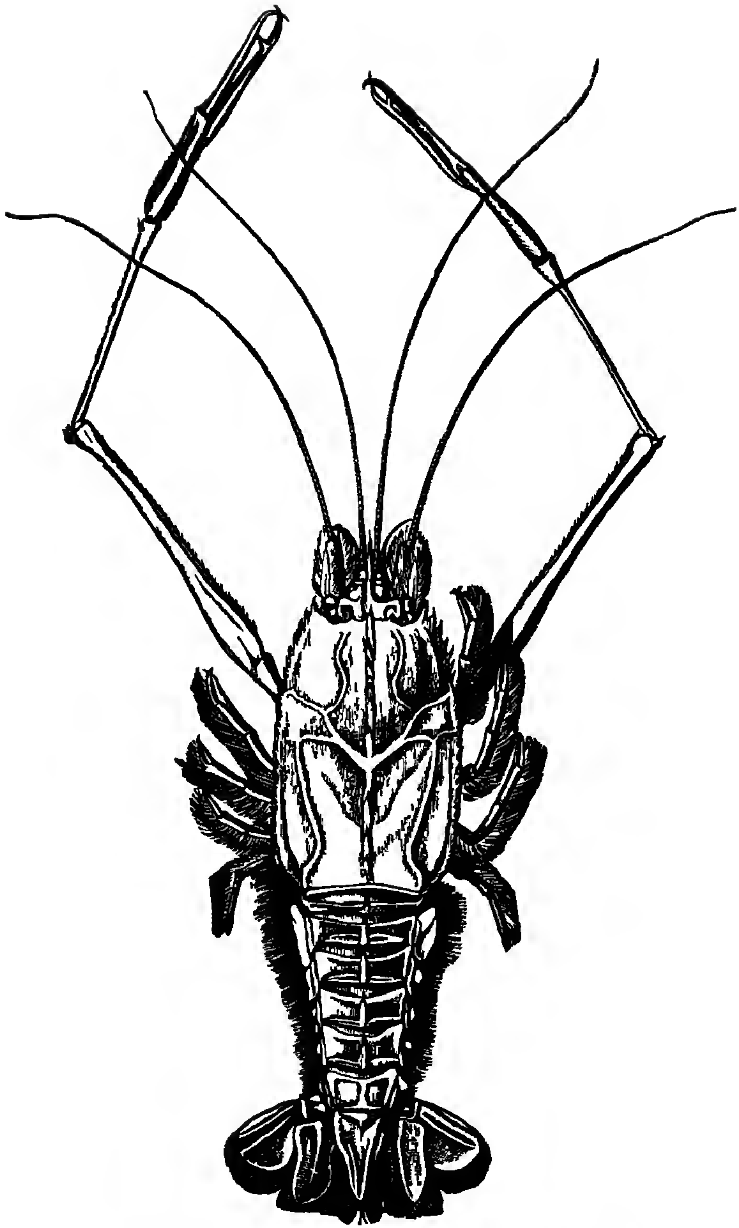


FIG. 178. Willemoesia, a Deep-Sea Lobster, of the Family Eryonidae Natural size

zone which have been proposed. The types of sea bottom usually met with may be arranged in a descending series, beginning with rock and passing through stones, gravel, sand and gravel, pure sand and muddy sand, to mud, varied by the occurrence of beds of dead shells or of the calcareous alga usually known as 'coral' (Lithothamnium). In any given district it is usual to find that each of the above-named types of bottom has its own special fauna, and that many species seem to recognize a more minute subdivision than man, whose observations are necessarily made from a distance, can appreciate. The reason for the preference for one type of bottom rather than another usually resolves itself into a question of support or of shelter, either for the species itself or for its prey. Of course, there are very many species that may be found indifferently on all sorts of bottom and under all kinds of conditions.

The connexion between the nature of the bottom and its inhabitants may be illustrated by an example. In some spots on the west side of the Irish Sea, when a haul of a trawl is made, at least 90 per cent. of the catch consists of the Alcyonarian or 'false coral', known as 'Dead Men's Fingers' (Alcyonium digitatum), while on the surrounding grounds only a few specimens are to be met with. The reason of this is clear. These spots where Alcyonium flourishes are beds of dead shells, mostly scallops and spiny cockles, which afford a foothold for the swimming larva of the Alcyonarian when seeking a place on which to settle down. Incidentally, the local range of at least three other species is marked out at the same time; two Nudibranchs which feed on Alcyonium are always to be found in the neighbourhood of these shell beds, and also a small Isopod Crustacean which lives on the same species.

In the case of organisms which are free to move about,

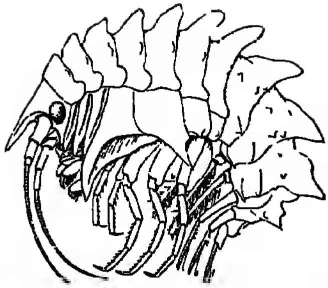


FIG. 179. Epimeria, an Amphipod. × 2

FIG. 180 Caprella, a Ghost Shrimp. Enlarged

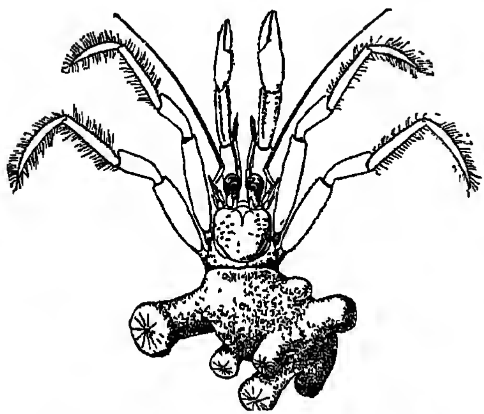


FIG. 181. Catapagurus, a Hermit-Crab, its posterior end in a shell, on which lives a colony of Anemones. × 2

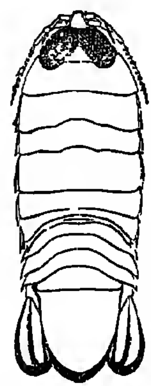


FIG. 182. Rocinel an Isopod. × 4

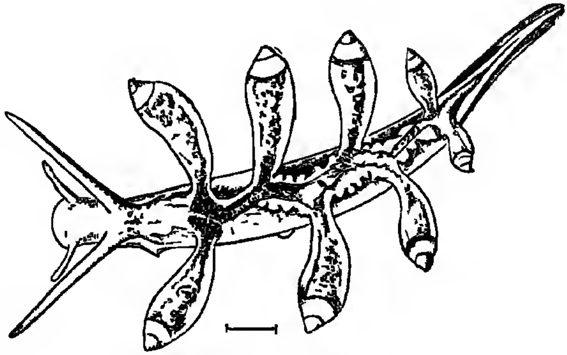


FIG. 183 Eolis, a Sea-slug. Enlarged

the reasons for one kind of ground being more suitable than another are not so evident. The Norway lobster, or Dublin Bay prawn (Nephrops norvegicus), which abounds on the mud covering the bottom of a great part of the Irish Sea, rarely ventures on to the adjacent sandy grounds; while the masked crab (Corystes), which frequents a clean sandy bottom, is never found on the mud. The circular crab (Atelecyclus) is not found on either sand or mud, but should be looked for in coarse sandy gravel. In these instances the animals find shelter by burrowing beneath the surface (though in the case of the Norway lobster this burrowing habit must be inferred, as it does not seem to have been established by direct observation), and the medium chosen is probably the one best suited to their excavating powers, or breathing apparatus.

The fauna of an area of soft mud affords many instances of animals, either specially modified to meet their peculiar conditions of life, or else adapting themselves to their circumstances without any special structural alteration. Leaving aside those species which are capable of burrowing beneath the surface, we notice that the peculiarities of a mud fauna are due mainly to the absence of any solid points of attachment or support.

This relationship between animals and their surroundings and between different animals inhabiting the same type of ground has in recent years attracted a good deal of attention and has been studied in great detail by Dr. C. G. J. Petersen, the Danish zoologist, and his followers. Dr. Petersen has designed an efficient grab dredge, which lifts from the bottom the mud or sand of a measured area with its contained fauna, and from the data furnished by a number of grabs the average distribution per square metre can be estimated for the contained animals, both those living on the bottom and those which

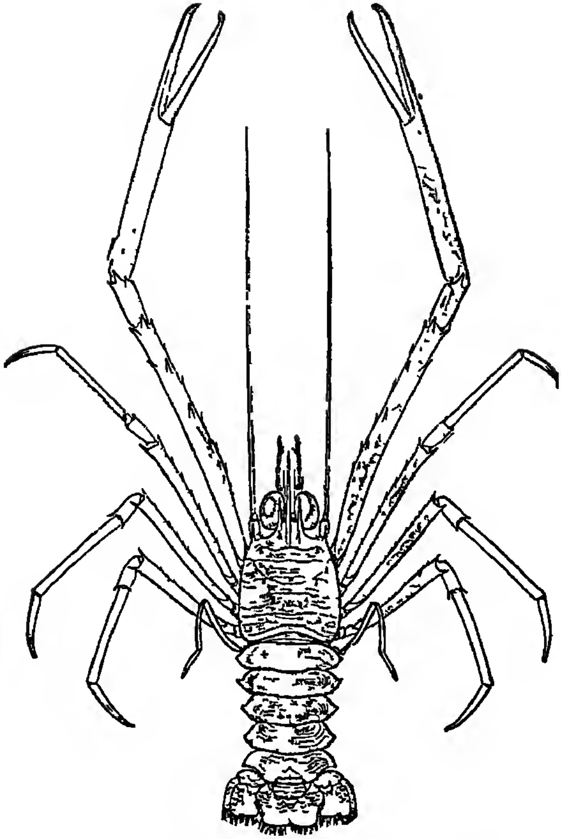


FIG 184 Munida, a Galatheid Natural size

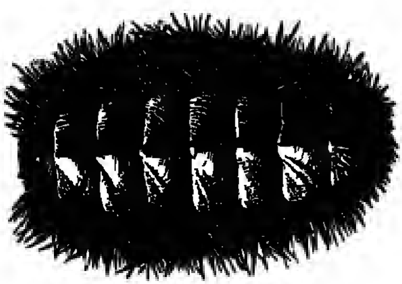


FIG 185 Chiton

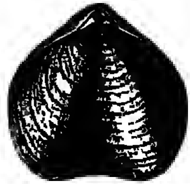


FIG 185a Terebratula, a Lamp-shell Enlarged

burrow not too deeply beneath it. By the aid of this instrument various communities of associated animals, usually, though not always, living at similar depths in or on soil of the same texture, have been defined, e.g. the community characterized by the echinoderms Bryssopsis lyrifera and Amphiura chiajii, living along with several characteristic molluscs in soft mud in deep water, or the Echinocardium cordatum—Amphiura filiformis community, living in coarser soil at lesser depths. This allotment of species to communities has been found to hold good with no great modifications in the North Sea, the Baltic, and the adjoining waters, but no doubt when the investigations are extended to more distant seas other species with similar habits will be found to replace those already defined for a limited area.

The Petersen Grab has also proved very useful in making clear the life stories of several common species and in showing how precarious a hold some of them have on existence. Mr. F. M. Davis, in his exploration of the fauna of the Dogger Bank, found that Spisula subtruncata, a bivalve mollusc which is the main food of the plaice on the rich feeding-grounds of the bank, forms there beds of vast extent in the shallower waters. Each bed is composed of individuals of the same age, and when first formed is densely populated, but in a few years is almost wiped out by the attacks of fish and other predaceous animals. Fresh beds are in the meantime formed by the settling down of the clouds of spat emitted from the older molluscs. The spat drifts for a week or so at the mercy of the current and then settles down wherever it happens to be. It is easy to see that some unusual set of the current might drift the spat from the bank to the surrounding deep water, where it is probable that it would perish and the bank would be left unstocked by that year's generation.

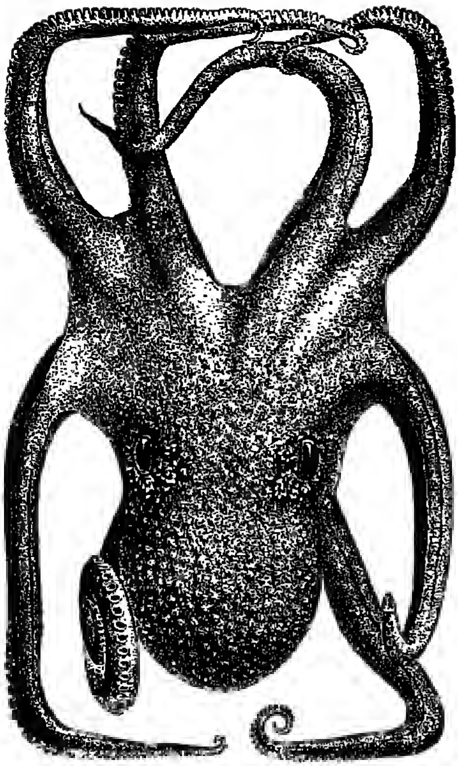


FIG. 186. Eledone. $\times \frac{1}{3}$

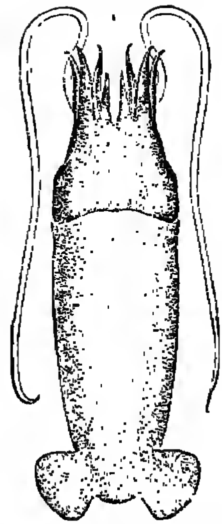


FIG. 187. Benthoteuthis, a Deep-Sea Squid. $\times \frac{3}{4}$

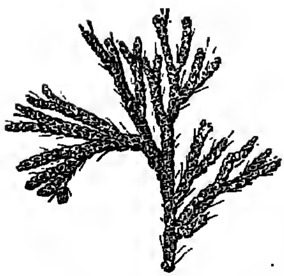


FIG. 188. Cellularia, one of the Polyzoa. $\times 2$

FIG. 189. Cellularia. Magnified

The failure from time to time of the Ceylon Pearl Oyster fishery on the Paars or shallow rocky banks in the Gulf of Manaar seems to have a similar explanation. The Pearl Oyster, in reality a kind of mussel, needs a clean rock for attachment, and unless a good swarm of spat should happen to be in the water over the Paars when the time for settling down is reached, a failure of the fishing some years later will naturally result.

The Deep Sea

Shortly after the edge of the Continental Shelf is passed, we begin to meet with members of the true deep-sea fauna, which peoples the abysses of the ocean. With the rapidly increasing depth the proportion of shallow-water forms becomes less and less, till at a depth of 1,000 fathoms there is hardly a species left of the abundant life of the Continental Shelf. Their place has been taken by a fresh assemblage of animals, which, as a whole, present a very different appearance. If, however, we take into account the very much altered conditions under which they exist, these differences are perhaps not so great as might have been expected. In fact, except amongst the fishes, and, perhaps, some of the sea-cucumbers and Crustaceans, there is hardly an inhabitant of the deep sea which differs so markedly from its nearest allies which live in shallower water, that, were its origin unknown, it could be said without hesitation to be an inhabitant of the abyss.

The physical conditions prevailing over the bottom of the deep sea are almost uniform, so far as we can perceive, through long periods of time and throughout all oceans. The darkness is absolute, or broken only by gleams of light from 'phosphorescent' animals. The temperature is very low, at most 3° or 4° F. above freezing, and constant. The pressure is enormous, upwards of 3 tons per square

inch at a depth of 3,000 fathoms. It is hardly necessary to point out that, once the tissues of an organism were adjusted to meet this pressure, it would be felt no more than is the pressure of the atmosphere by the inhabitants of the earth's surface. The effect of this pressure, combined with the low temperature, on the metabolism of the animal (the chemical changes connected with its vital processes), must, however, be very great. The water above the bottom is still or in very slow movement (unless, perhaps, in some narrow straits), and is not rendered turbid by any river sediment or by mud stirred up by currents from the bottom. The bottom itself is covered with a fine ooze, usually without rocks or other solid bodies to afford support to sedentary organisms. In the absence of any vegetable growth the inhabitants of the deep sea must be carnivorous, and as it is not possible for them to sustain life by feeding mutually on each other, we must look for some external source of supply. This is to be found in the constant rain of dead organisms which have lived and perished in the upper layers of the ocean. The existence of this constant supply of organic matter is illustrated by the fact that the oozes which cover the ocean bed over a large part of its extent (Chapter VI) are formed from the shells or skeletons of the microscopic Radiolarians, Foraminifera, or Diatoms, which swarm in the waters above. This does not mean that the whole of the food supply consists of microscopic matter, for in the upper waters representatives of almost every order of marine animals, from whales downwards, may be found.

Very little is known of the animal life in the deepest parts of the ocean floor, but the few hauls which have been made in depths of over 2,000 fathoms show that the fauna is comparatively poor both in species and individuals as compared with that to be found at about 1,500 fathoms,

where a rich invertebrate fauna, in which Echinoderms are predominant, may be trawled, though fishes are scarce. This is shown clearly by the results of the *Michael Sars* Atlantic Expedition, and the *Challenger* had a similar experience.

In the early days of deep-sea exploration it was believed by many naturalists that the unknown depths of the ocean would be found to harbour survivors of an earlier geological epoch which would fill gaps in the known pedigree of the Animal Kingdom. This expectation has not, save in a few instances, been realized, for, although an immense number of deep-sea species have been discovered, they are, on the whole, either very like those from shallow water or else have been specially modified in adaptation to the changed conditions of life. On account of this general resemblance of the abyssal fauna to the animals inhabiting shallow water at the present time, rather than to those of a remote geological period, it is generally believed that the inhabitants of the deep sea have migrated thither at some comparatively recent geological age, the migration probably beginning at the close of the Mesozoic Period, and continuing to the present day.

It is hard to point out any features in which, as a whole, the animals of the deep sea differ from those of more shallow waters. Their colours are, as a rule, peculiar. Fishes are usually black, while Crustacea are mostly red or pink. The Echinoderms show a great range of colour, from yellow through orange and red to crimson and purple. Uniform colours are the rule, rather than blotches or stripes, such as are often found in shallow water. These markings may perhaps be regarded as having a protective or warning significance, which would be of no advantage to an animal living in utter darkness. Many of the animals

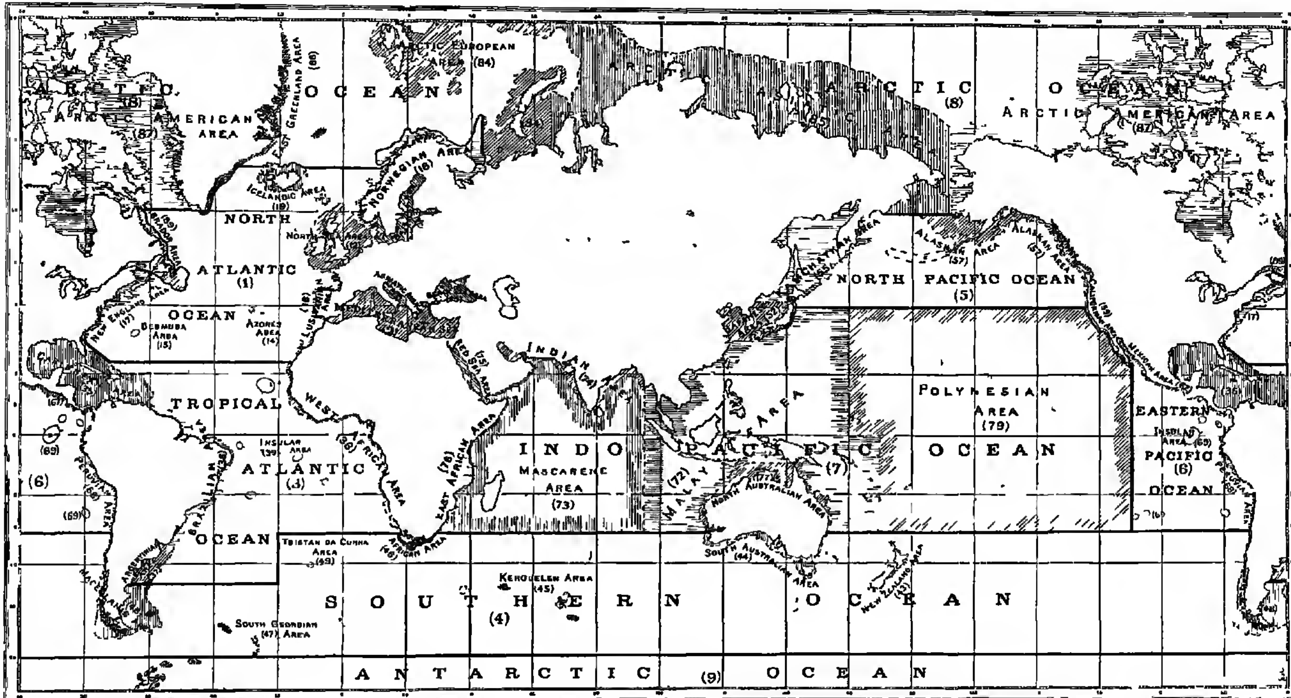


CHART XI—AREAS OF MARINE DISTRIBUTION

The areas here adopted for the purposes of the Challenger Society's Bibliography of Marine Faunas are based on what appear to be the natural boundaries of temperature, current, depth, &c, which affect the distribution of both floating and bottom animals

Facing page 304

themselves are blind, and probably burrow in the soft ooze, or live a sedentary life, clinging to hydroids, false corals, or sponges. Others have large eyes especially adapted—at least, in some cases—for the perception of faint gleams of light. These are probably more active and predatory types, guided to their prey by its own luminosity, or sometimes having themselves luminous organs, which serve as veritable searchlights.

While the deep-sea fauna, as a whole, is by no means of a primitive type, there are a few cases where it does seem that animals of an antique type have found in the deep sea a refuge from the more strenuous competition of the thickly inhabited shallow waters. This is notably the case with some Crustacea. The Eryonidae (Fig. 178), a family of flattened lobster-like animals, are the living representatives of a group of which the remains are abundant in the rocks of the Triassic and Jurassic Epochs; the Homolodromiidae of the deep sea appear to be the most primitive of the existing crabs, and resemble some found as fossils in Secondary Rocks; and certain deep-sea prawns (belonging to the families Penaeidae and Acanthephyridae) are probably of more ancient types than their relatives in shallow water.

Finally, the extreme imperfection of our knowledge of the fauna of the sea bottom in nearly all regions of the world cannot be too strongly emphasized. Even in shallow waters the smaller animals are almost unknown, except in parts of the North Atlantic and Mediterranean; and those who have the opportunity of dredging in depths exceeding 100 fathoms in any part of the world may be assured that any animals which they may find are likely to be of interest and value to specialists. The methods of dredging and trawling are explained in Chapter IX of this volume, and we need only mention here the importance

of carefully sifting the dredged material. The contents of the finest sieves should be preserved in bulk for subsequent examination in the laboratory. It is astonishing what wealth of living things may often be found by this method in mud which seems at first sight to be barren of life. It need hardly be said that the precise locality of each haul should be carefully noted, and, what is even more important, the exact depth and temperature recorded where possible.

A rare opportunity of obtaining specimens from the greatest depths of the oceans is afforded in the course of repairing deep-sea telegraph cables. These are often encrusted with sponges, corals, barnacles, and other organisms, while Crustacea, Mollusca, and Echinoderms are brought up clinging to them. The preservation of such specimens would yield much information regarding the fauna at depths which are otherwise only to be reached by costly and elaborately equipped expeditions.

VIII

EQUIPMENT

BY S. W. KEMP AND THE EDITOR

PRACTICALLY all oceanographic work, except heavy dredging and trawling at great depths, can be done from a sailing yacht, if furnished with a little steam capstan, such as is fitted to sailing trawlers.

In a sailing yacht without any power whatever, the collection of water samples, plankton work down to at least 500 fathoms, and dredging and trawling in shallow water can be carried on without difficulty.

But in a sailing yacht, whether with or without a capstan, the rig, tonnage, freeboard, and deck space are so important that it would be well to inquire beforehand from experts what branches of the work could be most suitably pursued.

With power available for propulsion as well as hauling, oceanic work will be done more easily, and more can be got through in the same time. It is not only true that no time is wasted in tacking between stations, but the handling of the ship when at work is much facilitated. In using most deep-sea instruments, especially if driven by messengers (weights which slide down the rope), it is most important that the rope should be kept vertically up and down, and not allowed to stream away as the ship drifts.

With plenty of steam on board, the capstan can be replaced by a steam winch or windlass, with the result that work can be carried on at far greater depths, and far more rapidly and safely.

Supposing that there is *no* deck engine already on

board, the owner will find that a good winch can be utilized for practically every kind of work—thermometers, water-bottles, soundings, tow-nets, dredges, and trawls, as well as for hoisting boats and anchor, cargo and coaling work. With winches (as with much other gear), the owner, master, and engineer must settle the exact specification, according to the work to be done. We can only give the most general indications as a guide.

One may use (1) either a regular trawling winch, on the barrels of which the rope is stored; (2) or a cargo winch, which will haul the rope but not store it. Of these two types, there is no doubt that the regular trawling winch is much to be preferred. It will not only serve for the ordinary work of a cargo winch, but when scientific work is required it will save deck space and hands.

We figure a commercial trawling winch, showing the usual two hauling and storing barrels in the centre of the engine. For really deep-water work this type requires some modification. In the first place, if required for trawling and dredging only, a single large barrel is better than two smaller barrels, the divisions between the latter having been known to burst and cut the rope under pressure. In the second place the brake wheels should be cast solid with the barrel ends, and strengthened by radiating ribs, in order to resist the enormous lateral thrust of a great length of rope wound under tension. But if it is proposed to use closing tow-nets and other apparatus with small messengers, which require a slighter rope (p. 234), in addition to trawl and dredge, it might be well to retain the double barrel, using one barrel for each rope, and strengthening the division between them. In this case the barrels should be clutched separately, which is not always the case with commercial trawling winches.

A cargo winch can be used for all deep-water work if it

carries a largish, deeply grooved drum for winding, of (say) 18 or 24 in. diameter, in addition to the ordinary small barrels. This drum will only carry two or three turns, and the wire must be taken up, as it comes off the

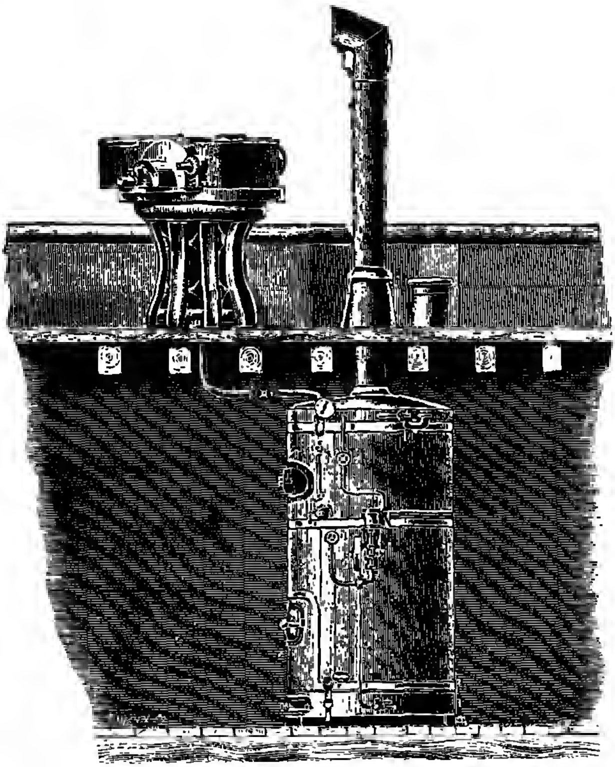


FIG. 190. Steam Capstan for use with Sailing Yachts: suitable for the largest Trawls

drum, on to a storage reel of some kind. It is no small labour to reel up 1,000 fathoms or so of wire rope by hand power, and as a rule it cannot be taken up as fast as the winch can deliver it; the method is therefore wasteful of both time and labour, and the storage reel should, if possible, be driven mechanically. If a fairly powerful cargo

winch is already on board, which it is not desired to displace, we should recommend that a one or two horse-power steam engine or motor should be fixed behind the winch, so that it could drive whichever storage reel was required at the moment. Another plan which has been suggested is to drive the storage reel by an endless rope (or swifter) from the small barrel of the winch, the rope being kept taut by passing through a block against which a weight pulls. When the reel tends to run too fast, the rope-drive will slip and so provide the necessary compensation.

It should be remembered that with a cargo winch there is much more wear on the warp than with the trawling winch. In using either of the above methods care should be taken to reduce the slip on the driving drum to a minimum.

Storage reels for the above purposes should be of extra solid construction and provided with a powerful hand brake. Most of the patterns on the market are only intended for occasional use, and are consequently of the very lightest build, with inferior bearings.

A. *Deep Sea*

1. DREDGING AND TRAWLING

As this is the heaviest and in many respects the most difficult part of oceanic work, it should be the first to be considered.

Next in importance to the winch is the wire rope to be employed; this must be flexible, lest it kink and snap when the strain is taken off, as, for example, when the trawl touches bottom. Flexibility implies several strands, each of numerous wires, and this unfortunately involves weight. Fig. 192 shows a section of a suitable rope, and

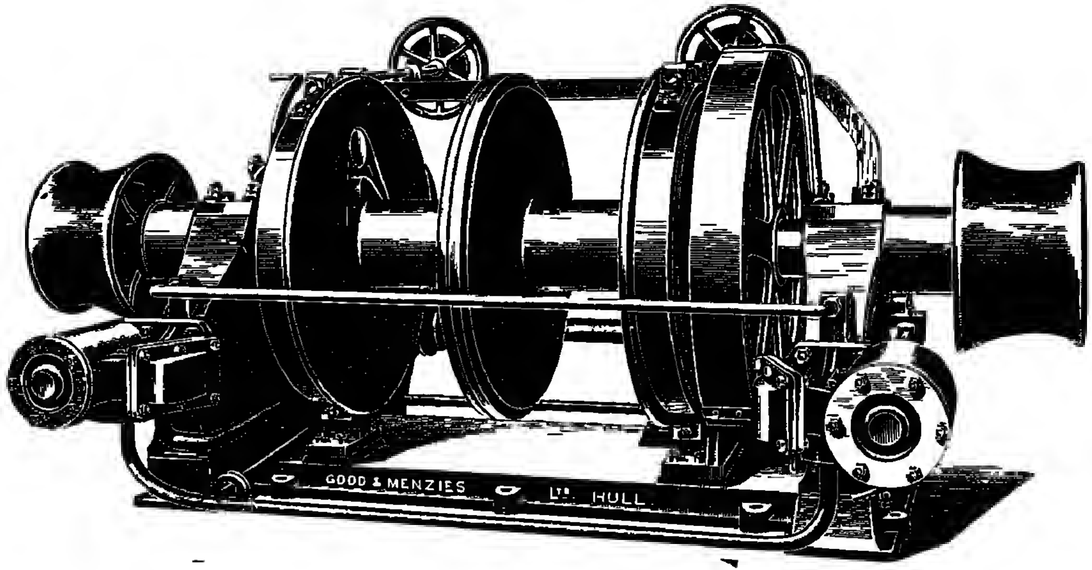


FIG 191 Commercial Trawling Winch

displays six strands of twenty-four wires each (6×24); each strand has a hemp core, and the whole rope a hemp heart.

Before selecting a rope, it is of great importance to select a manufacturer with care; it is not every firm which understands the special demands made upon a rope by deep-sea trawling.

The selection of a rope will, of course, depend largely upon the depth to which it is proposed to work, the probable character of the bottom, and the size of the dredge or trawl. If it is proposed to work down to but not over 1,000 fathoms, a single length of 1,500 fathoms of 1-in. rope, with breaking-strain about 3 tons,[1] would probably serve the turn.

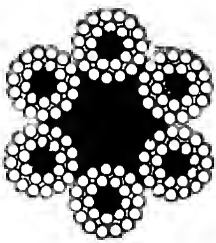


FIG. 192. Section of Wire Rope

Work at anything over 1,000 fathoms implies an 'expedition' rather than a yachting cruise, but for work to 2,500 fathoms the following combination may be suggested: 1,500 fathoms of 1-in. rope at the trawl end, 1,000 fathoms of 1¼-in., and 500 fathoms of 1½-in. at the winch end, all shackled together;[2] a special shackle is made for this work. The object of this combination is to strengthen the rope where the heaviest strain comes, and the total result is as follows:

[1] It may be mentioned here that H.M.S. *Challenger* used hemp ropes of 2 in. and 2½ in. circumference, with breaking-strains of 1 ton 12 cwt. and 2 tons 6 cwt. respectively. For shallow-water work was employed a rope of 3 in. circumference, with breaking-strain of 2 tons 11 cwt. But it must be remembered that in water a hemp rope carries much more of its own weight than a steel rope. Sir John Murray informs us that the rope was hauled at the rate of 1,000 fathoms per hour, and that during the three and a half years' cruise, when trawlings and dredgings were made at 354 stations, there were only eleven cases of parting of the rope. Wire ropes were first used for such work by Agassiz in 1877.

[2] Owing to the shackles (or splices) such a rope could not be used below 1,500 fathoms for closing-nets or similar apparatus worked by messengers.

	Weight ton	Weight cwt.	Breaking-strain tons	Breaking-strain cwt.
At sheave	1	17	8	0
Above first shackle . . .	1	7	8	0
Below " " . . .	1	7	4	14
Above second shackle . . .	0	13	4	14
Below " " . . .	0	13	3	11

Whether the rope be stored on the winch-barrel or on a separate reel, it should be carefully and evenly spread as it comes in. In hauling heavy gear, especially where the warp is wound directly under considerable tension, the spreading is best done by means of a mechanical spreader; this apparatus is sometimes supplied by the manufacturers of trawling-winches. In some patterns the wire is spread by a long steel fork, which moves, either mechanically or by means of a handle fitted to a long pivoted arm, across the face of the barrel. In this type the friction on the warp when hauling heavy weights would be very destructive; a carrier holding three rollers (two upright and one horizontal) should be substituted. In a simple type, which one of us is able to recommend, the carrier and rollers are made to travel on a slide by the rotation of a long screw-shaft, actuated by a handle from one side. The work can be done with more labour by using a snatchblock on a lanyard or spar; but while this method will be found efficient for light work, or for reeling wire that is not under tension, it is scarcely applicable when hauling heavy gear, for in such cases the strain is so great that the united efforts of two men and a 'purchase' will be required.

Greasing is also an essential to the preservation of wire rope. As it comes in, it should pass through well-oiled cotton-waste. A mixture of equal parts of tallow and castor oil, applied warm, is strongly recommended, or one of the special oils supplied by the rope manufacturers; the

ordinary fluid machine oils seem to disappear at once, and should be renewed daily if used at all.

It should be stipulated with the makers that all wire ropes be sent properly coiled on a reel of some kind. As soon as received, if the rope is to go on the trawling-winch, it should be paid on to the winch barrel under a steady strain with the reel revolving; under no circumstances should it be paid on with the reel flat, or from a coil. Before being used for trawling, the whole length should be run out at sea, and carefully reeled up under a fairly high strain.

Two other pieces of gear are advisable—an accumulator and a recording sheave. The old type of accumulator consisted of a number of stout cylindrical rubber straps between two boards, the whole slung from a derrick or spar, and carrying the block over which the trawl rope runs out-board; the object of this was to lessen any sudden strain on the rope due to the trawl hitching, and to warn the man in charge of such strain. Nowadays the less bulky and more reliable steel spring accumulators are to be preferred. If trawling from a derrick, the topping lift, passing over a block stropped to the mast, is brought down and made fast to the head of a long steel spring, rigged up against the mast.[1] A sudden strain on the rope pulls down the derrick head, the spring yielding. Such an indication will often enable the gear to be recovered before it is seriously damaged, while with very severe pitches the warp is (probably) saved from snapping.

For really heavy trawling a nipper may be substituted for the accumulator, or used in conjunction with it. This nipper (Fig. 193) is attached by means of a hemp rope to the winch or some other solid deck fixture, and the

[1] This arrangement is figured in Report of the Siboga Expedition, 'Description of the Ship', by Lieutenant G. F. Tydeman, Plate I.

slack tripping line is also shackled to the same support; the accompanying figures will explain the method employed.

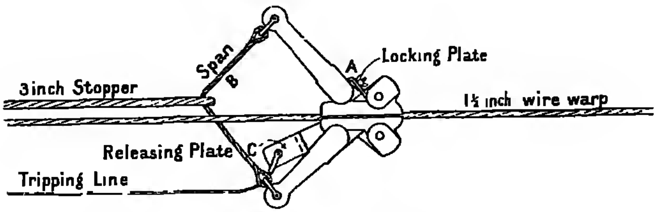


FIG. 193. Nipper for Heavy Trawling

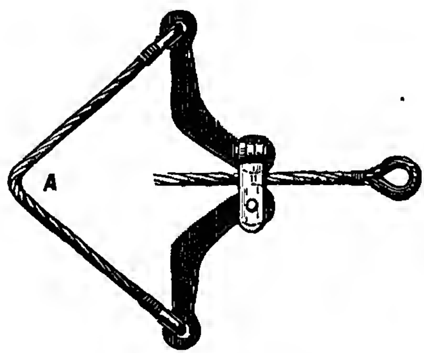


FIG. 194. Small Nipper Rendering

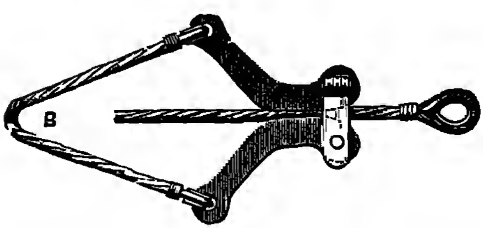


FIG. 195. Small Nipper Gripping

Any undue strain causes the hemp rope to break, allowing the wire to pay out from the drum or reel (if the brake is left open), while the nipper is checked by the tripping

line, and either falls to the deck or allows the wire to render through it, according to the particular make fitted. A small nipper will also be found useful for holding the warp in the event of anything going wrong; Figs. 194, 195 illustrate a simple form which may be employed for this purpose.

A **recording sheave** (or meter wheel) of some kind is necessary for work in deep water. This need only consist of a strong sheave of known circumference (as 1 meter), to the spindle of which is affixed an ordinary engine-room counter, but the specially made patterns with roller bearings and more durable recording mechanism are preferable. For working heavy vertical or mid-water nets this sheave may be bolted to the deck, but for work of a lighter character it may be slung from a davit in place of the ordinary snatchblock. For bottom trawling a recording sheave can often be dispensed with, for a sufficiently good estimate of the amount of warp paid out can usually be made by eye. When, however, long lengths of heavy wire rope are to be used for various purposes, it will often be convenient to mount a counter on a large revolving bollard securely bolted to the deck; with this arrangement shackles and bridles can, if desired, be wound on to the winch-barrel. The revolving bollard should be fitted with roller bearings and should be made of specially hardened steel.

All rollers and sheaves should be brass-bushed if possible, and they should be kept drenched in oil; it is astonishing how soon oil disappears when 1,000 fathoms of rope are being paid out, and what disaster attends a block jammed for want of it.

2. SOUNDING

A sounding should always be taken before any gear is shot. In surveying vessels the deep-sea sounding machine is generally rigged in the bows: it can be driven by a swifter from the deck engine. Some forms of deep-sea sounding machines—for example, the Lucas (used by the Hydrographic Office), the Sigsbee, and the Le Blanc—can be driven by their own little engines.

For deep soundings single-strand piano-wire is nearly always used, but it is very stiff, and liable to kink and snap if not checked the moment that the lead touches bottom. To get good results a considerable amount of practice is necessary even with the best machines. In the Lucas machines (both for deep and shallow water) the jib-sheave is mounted on a movable arm which actuates a hand-brake when it is elevated (see Fig. 197). This arm is held in position by two springs and the tension of these can be regulated by a screw. When sounding, the tension is slowly increased to balance the weight out-board, and with experience in manipulation the machine can be so regulated that it stops automatically as soon as bottom is reached.

For really deep-sea sounding it is advisable to use a heavy sinker of at least 50 lb., which is detached on striking bottom and left there; this method enables the wire to be hauled rapidly, and without danger either of breaking the wire or of bursting the barrel on which it is reeled up. The sinkers are made of cast iron.

Several types of deep-sea sounding leads are in use, their form being dictated by the fitting employed to bring up a sample of the bottom (cf. Chapter VI, 'The Sea Floor'). For the latter purpose have been employed a cup (not now in use); a heavy tube, which, when being hauled,

is closed below, either by a butterfly valve or a cock; and a snapper, consisting of two tightly fitting buckets which grip a bottom sample. The second of these is represented in Fig. 151, p. 243, the third in Fig. 196.

The wire should be well greased. Very great care should be exercised in spreading the sounding wire evenly on the barrel, and the same precautions taken in paying it on to the barrel from the manufacturer's reel, as in the case of wire rope.

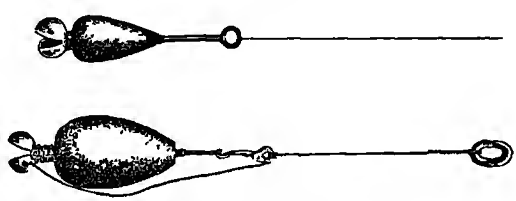


FIG. 196. Sounding-Leads, with Snapper for Collecting Bottom Sample. (Lucas Snappers.)
The lower lead has a weight which is detached on striking the bottom

3. OTHER WORK

It is not economical either of time, labour, or the life of a rope, to use a heavy rope where a lighter one would do the work, and a 1-inch rope is not well adapted for other uses than trawling, dredging, and big tow-nets. A lighter and cheaper type of rope can be used for reversing thermometers, current meters, water-bottles, and tow-nets up to 2 ft. in diameter. A suitable rope for such work would be 4 mm. in diameter, composed of six strands each containing seven wires, with a breaking strain of $19\frac{1}{2}$ cwt. and a weight of 3·7 lb. per 100 ft. (in air). By reducing the number of wires a much stronger rope of the same diameter can be spun, but it will lack flexibility.

B. *Shallow Water*

The hints already given relate to the most difficult and troublesome part of all oceanographic work, that which involves the most power, time, weight, storage-space, skill, care, and expense. If deep-sea work is the most ambitious, it is also the most interesting; if it is the most difficult, it is also the most needed, and the most productive of striking results.

On the other hand, excellent and valuable work can be done at small depths in almost any part of the world. Even in home waters little has been done systematically outside the 100-fathom line; beyond home waters (except in one or two favourite areas) any one with a rowing-boat and a little apparatus can add materially to knowledge.

1. DREDGING AND TRAWLING

In shallow water, down to (say) 200 fathoms near land, it must be remembered that if the net catch on a rocky bottom, a breeze acting on the freeboard of a large yacht or steamer will impose a very great strain on the rope; a trawl full of stones or mud is also a menacing possibility. For such work a 1¼-inch or 1½-inch rope, with a breaking-strain of 4 to 8 tons, is desirable; the lifting power of the deck engine can be somewhat reduced, but an accumulator or some similar protection is certainly required. With this gear a yacht can work in as little as 3 or 4 fathoms, if the water is known to be clear of dangers. But in uncharted waters near shore, and particularly in coral seas, the owner will naturally not risk his yacht close in shore. A small sailing boat or steam pinnace, using good tarred 1½-inch hemp rope, hauled and coiled by hand, can easily work an 8 to 10 foot beam trawl, or a fairly heavy dredge; even a yacht's punt can work a small dredge. Very excellent

work round foreign ports can be done in this most unambitious way by any one. One of the most distinguished marine naturalists used a light hand dredge about 10 inches long, which he cast like a lead as far as possible, and hauled at once.

2. SOUNDING AND OTHER WORK

In Fig. 197 is shown a small sounding machine, with capacity of 200 fathoms of piano wire, 22 gauge. A 20-pound sinker, not detaching its weight, carrying a snapper or a valved tube, will suffice.

A small sounding machine could be utilized with a fine stranded wire for thermometers, light water-bottles, current meters, &c., down to 200 fathoms (if the barrel will take so much); but valuable instruments should not be trusted to piano wire in a small ship with a short roll. A cheaper form of reel can be knocked up in plain galvanized iron. For some work it is enough to mark the wire by whippings, but if messengers are to be used this marking will not do, and a recording sheave of some kind will be needed; an excellent little sheave is made for the International Commission for the study of the North Sea, which records the length of wire out in metres.

The reel or sounder can be fixed close to the ship's rail, or if fixed amidships the wire can be led over the recording sheave slung from a davit or from a spar, which can be swung inboard when the gear is up, in order to enable the instruments to be conveniently attached and detached.

Lighting. If there is a dynamo on board, a 'cargo cluster', with enamelled iron shade and flexible connexion, is very useful for working at night. Heavy nets should never be shot at night until the whole crew is thoroughly well practised in the use of the gear; a man can easily lose

his life by getting a turn of the warp or spans round his leg. A portable 'electric torch' is very useful for reading the log, &c., at night.

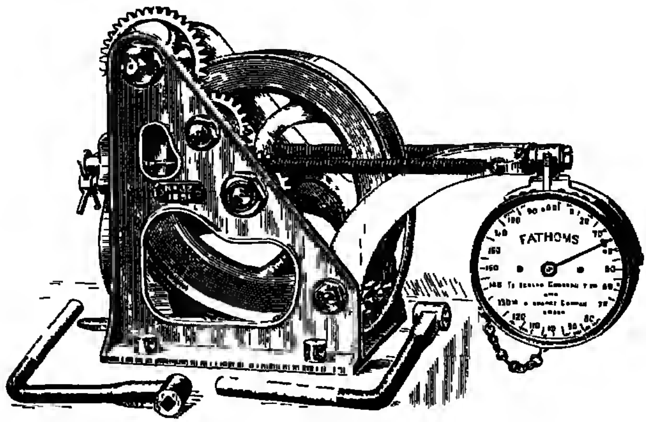


FIG. 197. Lucas Sounding Machine, hand-driven

C. *Laboratory Fitting*

Some sort of place will have to be used as a laboratory, where the scientific log can be written, collections preserved, labelled, and packed, &c.; so that a few notes may be here added on fitting it up as a laboratory.

It is perfectly possible, by a little forethought, to do solid work, and yet to keep the yacht as spick and span as any owner can desire.

The position of the laboratory and its fittings will depend entirely on the rig and build of the vessel. It should be amidships and on deck, if possible. It cannot have too much light. A poop deck-house makes an excellent laboratory.

A very important matter is the work-table; this can be either fixed or swinging, and both have their supporters. A stout table, of the kitchen type, with a well-oiled top,

and a large drawer for charts and flat papers, and firmly bolted down, has this advantage over the swinging pattern —that the space below can be fitted up with pigeon-holes of various sizes to take apparatus and accessories of all kinds. Half at least of the surface should be divided up permanently, by fiddles about 3 in. high, into compartments suitable for the bottles or other apparatus required. If this is the only table in the laboratory, the other half should be left clear for writing, charting, drawing, &c., but a separate table, for writing and for microscopic work, is a great boon.

If a swinging-table be preferred, a stout rail, level with the table and about $1\frac{1}{2}$ in. clear of its edge, fixed at the corners to stanchions from the floor, will bring up any one lurching against it in a heavy sea.

If there is a dynamo on board, a cluster of lamps should be over the centre of the table; but a hanging oil-lamp should not be arranged to throw a shadow over the writing-table.

The particular work which it is proposed to attempt will, of course, determine the character of the bottles and apparatus to be kept in the laboratory; but preserving jars, and glass tubes, are needed in all kinds of zoological and botanical work, and should be racked in quantities round the walls. Large bottles of killing and preserving fluids should be racked together. A 2-gallon milk-can, with tap below, and a filter of fine boulting-cloth at the top, is handy for the necessary store of clean water, whether salt or fresh (ship's fresh water not being ideally clean); it should be emptied and refilled every day. An enamelled slop-pail, with a top, should also be racked in a handy position to receive mess and waste fluids of all sorts.

1. **Plankton.** Special receptacles in the fiddles of the

work-table should be made to take two or three jars or deep dishes into which the contents of the tow-net tin are emptied for sorting. Other compartments should take those smaller bottles in which the larger organisms are to be pickled. Empty the 'tin' into the jar or dish with plenty of filtered salt water, pick out the larger specimens with lifter and pipette, and pickle them with as much elaboration as time allows (see Chapter XI, 'Preservation'). Add a few drops of undiluted formalin to the jars, and stir the contents gently till they are moribund; they are then allowed to settle. Pour off superfluous water, and transfer them to a wide-mouthed, smaller bottle (say 16 oz.), and fill up with 2 per cent. formalin. Later on, pour this off, and transfer the catch to the storage bottle, and fill up with 7 per cent. formalin.

The use of a compound microscope for live material is usually impossible, except in harbour, but a little 'dissecting microscope', with lenses multiplying 6 and 10, or 8 and 18 diameters, is extremely useful; it can be clamped to a fixed table, or swing in gimbals.

2. **Dredging and Trawling.** In this somewhat messier work the contents should be emptied on to an old sail, to save the deck. It is advantageous to lay this over a fish-fiddle (say 4 × 3 ft.), fixed, when wanted, against a hatch, and to run a coaming 2 in. high round the hatch, which can then be used as a table.

When the material obtained by the trawl or dredge has been deposited on deck, an immediate effort must be made to sort the heterogeneous assemblage of animals which is revealed. Scarce or fragile specimens should be transferred at once to glass jars or enamelled dishes. Fish may be placed in baskets, and the commoner invertebrates similarly treated, or stacked in an enamelled fish-kettle or slop-pail in sea-water.

Fish should all be measured to the nearest centimetre, and entered in the scrap log-book along with an enumeration of the invertebrates. Unless the identity of the species is established beyond all doubt, samples should be preserved. It is evident that numbers of indeterminable forms will be found; these may be entered as Gadoid A, Asteroid A, &c. The same species occurring in subsequent hauls should be referred to in the same way, but unless the identity of the two forms is certain, a sample must again be preserved.

When possible the stomachs of fish should be examined, for, apart from the light which is thus thrown on the food supply of the species, they occasionally contain invertebrates which are seldom or never found in any other way.

Search should be made for hermit crabs and worms resident in the dead shells of molluscs, and for encrusting animals living on stones or other debris. As a rule it is best to avoid attempts at extraction or removal.

The comparatively large animals, obtained in bags of sprat meshing, may be dealt with in the same way, but the sorting of the material collected by the fine-meshed nets usually demands so much time that immediate treatment is out of the question. In such cases it is best to transfer the whole to a jar containing 5 per cent. formalin, until a more favourable occasion arises. It should be remembered that formalin, even in a 5 per cent. solution, is sufficiently acid to act as a decalcifying agent; all animals which are liable to injury from this cause should be transferred as soon as possible to 70 or 75 per cent. alcohol.

The sand, mud, or ooze, which is sometimes brought up in considerable quantity by the trawl or dredge, generally contains a considerable number of animals. For the treatment of this material sieves must be employed;

the process is rather laborious, but the results are as a rule eminently satisfactory. It is best to obtain a set of four sieves (with different sized meshes), which may be employed successively, using the coarsest first. The sieves should be made of brass wire gauze, and are more convenient if fitted with handles (Fig. 152). The coarsest should have meshes about $\frac{1}{4}$ inch square, the finer patterns with eight, sixteen, and thirty-two meshes to the inch. It is advisable to preserve a sample of the ooze in alcohol, for many minute organisms will pass through even the smallest of the above meshes. A stream of water from a service pipe may be turned into the sieve, or it may be dipped repeatedly in a bucket of water. Shaking is very destructive and should be avoided.

Samples of stones, sand, mud, or ooze should always be preserved; small canvas bags are useful for this purpose.

3. Much valuable work on the chemical and physical conditions of the sea and the nature of the ocean currents can be carried out by quite small vessels. The auxiliary ketch *Armaur Hansen*, of only 60 tons gross, has made several summer cruises in the north-eastern Atlantic between Norway and the Azores; from the data of temperature and salinity of the water which were collected at various depths the current system of this ocean has been mapped. The necessary equipment for this work is relatively simple—water-bottles, thermometers, meter-wheel and a drum of fine wire with some motive power for reeling it in, since it is desirable to be able to obtain samples down to a depth of 1,000 meters or more. The analysis of the collected samples is usually carried out on shore. Much could be added to the existing sum of our knowledge of ocean currents by a vessel so equipped, which had time at her disposal to stop for one or two hours at a series of positions in the open ocean.

4. **Storage of Specimens at Sea.**[1] The larger and rougher specimens obtained by dredge or trawl, after the necessary preservation (Chapter XI), should have their label tied on to them, and then be wrapped in cheese-cloth and stored in spirit or formalin. It is handy to have on deck for this purpose an enamelled tank, or one made of wood and lined with lead (zinc tends to pit with formalin). The lid should fit on to a thick rubber flange, and may be held down by wedges driven under the cross-stays of the tank. Trays of lath inside serve to distribute the pressure of the upper layers of specimens. A useful size of tank is $3 \times 1\frac{1}{2} \times 1\frac{1}{2}$ ft. high. On a long cruise the contents of this can be occasionally transferred to barrels and headed up; to be sent home or stored in the hold.

Large but more delicate specimens can be stored in stoneware jars with very wide mouths; these are made in various sizes, and the lid is screwed down tightly on to a rubber flange by an iron clamp and thumbscrew. Two 4-gallon jars of this type, racked in a padded box, since they are brittle, will hold a very large quantity of material.

Sweetmeat jars, with a cork ring, are not to be recommended for prolonged storage where they cannot be constantly examined, unless tied over with bladder.

Many kinds of fruit-preserving jar are on the market, ranging in capacity from $\frac{1}{2}$ lb. to 7 lb., and some of these are very well adapted for the storage of specimens. The best have a glass lid resting on a rubber washer and kept tight by a screw-flange. This flange must be kept greased or it will rust rapidly. Wide-mouthed bottles (4, 8, and 12 oz.), fitted with corks, are often used for small specimens and plankton, but the cork, even though sealed with wax, is always a source of danger. Plankton may be

[1] For further information see pp. 404–9.

preserved in small jars of the type mentioned above, and small specimens are best placed in unshouldered glass tubes. These tubes should be filled to the top with preserving fluid, and plugged (without leaving an air-bubble) with balls of cotton-wool wrapped in tissue paper. They may then be stored together in a large jar, also full of fluid.

IX

DREDGING, TRAWLING, AND OTHER METHODS OF FISHING[1]

BY E. J. ALLEN AND S. W. KEMP

Dredging

DREDGES are suitable for the biological investigation of all grounds that are too rough to admit of trawling; they are very serviceable for obtaining samples of the bottom, and for testing the nature of unknown localities.

Many different patterns of frame are used for dredging, but these, for the most part, only differ from one another in unimportant structural details. The best type for all ordinary purposes is known as the double-sworded oyster dredge. Fig. 198 shows an example of this type, which was used by the *Porcupine* Expedition nearly sixty years ago, and the pattern has not been modified to any great extent since that date. The essential features of this type of dredge are the obliquely set blades or swords, on both sides of the mouth, the rings by which the net is attached (these prevent the edge of the bag from chafing when working on the bottom), and the loose connexion, which allows free lateral movement, between the bridles or arms and the frame. The whole instrument should be strongly made of wrought iron. Frames about 2 ft. long and 6 in. broad are suitable for in-shore work from small boats. For work at depths from 10 to 100 fathoms patterns from 3 ft. to 3 ft. 6 in. long and 8 to 9 in. broad are useful, while for very great depths large heavy makes up to 5 ft. long and 1 ft. broad are recommended.

The term naturalist's dredge may be restricted to a

[1] The Editor is indebted to Mr. F. M. Davis for revising the portions of this chapter on trawling and other methods of fishing.

form of frame which differs from the foregoing only in the absence of swords. The effect of this is that the straight edge of the frame tends to skim the surface of the ground instead of biting into it. This type has been almost entirely superseded by that mentioned above.

The **conical dredge** is designed to dig into the soil; of this it brings up a good sample, together with specimens of burrowing animals.

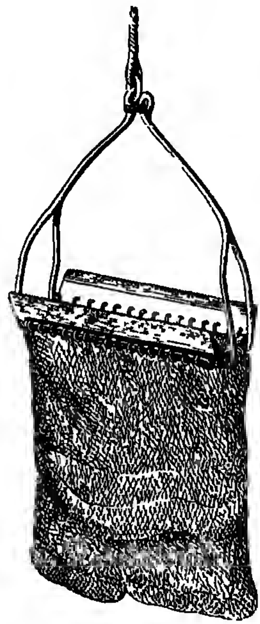


FIG. 198. Ball Dredge

The bag or net which is fastened to the dredge should be quite as long as, if not longer than, the frame, and should not be tapered behind. It may be made of strong manila trawl-twine of 2-inch mesh,[1] but a most suitable bag may be constructed from the cod end of an old trawl; this is usually easily procured and fitted. Loose chafing pieces attached to the outside are very useful, and save a great deal of wear and tear. For catching small animals and for use on smooth ground, a lining of sprat netting of 1-inch mesh, or even finer, may be fitted inside the bag (some firms stock an extra stout make of sprat netting, which is excellent for this purpose). The lining should be made fully as large as the outer bag, so that the strain is taken up by the latter.

Two small bags may also be fitted in the tail end of the lining; one of these is made of shrimp netting, and is designed to catch some of the smaller organisms which

[1] Meshes are measured diagonally when the net is stretched out; thus 2-in mesh means openings of 1 square inch.

would pass through the 1-inch mesh, while the other is made of sacking or stout canvas, and preserves a sample of the sand or other fine bottom material.

The two main bags—of trawl-twine and sprat netting—are lashed to rings at the back of the dredge, or they may be fastened directly to the frame by means of seizing wire. Each bag is opened or closed behind by means of a running string through the meshes. The small bags are stitched in position through both the main bags, and their ends are secured by a lashing.

The nets for small frames for use in shallow water are generally of a simple pattern. For these a piece of the cod end of a shrimp-trawl or the extra stout sprat netting mentioned above is suitable, with or without a lining of mosquito netting.

For the conical dredge a strong canvas bag is recommended. Dredges used in deep water should always have a piece of chain fastened to the end of the bag to prevent it getting foul of the frame while being lowered to the bottom, and this device is also useful at all depths when the net is new.

A tow-net made of cheese-cloth, with a strong cane ring, is sometimes fastened to the dredge. It is usually attached to the shackle at the end of the warp, with a strop sufficiently long to allow it to lie with its mouth a little behind the frame. By this arrangement the tow-net is designed to catch the small animals disturbed by the swords of the dredge. This method has been known to produce most satisfactory results, but the safe recovery of the tow-net is decidedly uncertain.

Tangles (or swabs) consist of lengths of hemp rope teased out, and fastened to the end of the bag or to an iron rod attached by chains to the frame. Starfish and other animals become entangled in the threads of the

hemp, and are thus drawn to the surface. Tangles were very highly spoken of by the naturalists on the *Challenger*, but in recent years they have not been much employed.

The dredge should be attached to the warp in the following way: The eye at the end of one of the bridles is secured to the eye at the end of the warp by means of a screw shackle, and the other eye is made fast merely by a strong strop or lashing of trawl-line. This arrangement is invaluable in the event of the dredge becoming fast among rocks, for in that case the lashing parts and the frame is drawn along sideways, thus usually clearing the obstruction and preserving the dredge from injury.

In 50 fathoms of water or less it is usually best to pay out warp to the extent of two or three times the depth; in deeper water less is required, and when working in soundings of 1,000 fathoms or more, 400 or 500 fathoms in excess of the depth will be found sufficient. In many localities, however, the nature of the bottom is so extremely rough that, if this amount of warp is given, the strop parts on every occasion. On such grounds it is advisable to pay out only a little warp in excess of the depth, and, after the ship has been stopped, to ascertain if the dredge is biting by holding the warp.[1] More warp may then be given cautiously if required.

Shooting and Towing

Sailing Yachts. Always tow with the tide if possible. With a moderate amount of way on the boat throw the dredge over on the windward quarter, and pay out a sufficient length of warp. Make the warp fast with a stop of small rope, but be sure to have the end well secured inboard, so that if the stop parts the whole will not be lost.

[1] By holding the warp it is often possible to feel a heavy dredge working, even at depths of 500 fathoms.

Tow slowly, feeling the warp from time to time to make sure that the dredge keeps on the bottom. If the dredge comes fast, lower sail if possible, pass the warp up to the bow of the boat, and haul in until it clears. If it still cannot be got free, try hoisting sail and beating back over it.

In working from small boats it is safer always to lower sail before hauling.

Steam Yachts. In small vessels it is best as a rule to tow from the warping-chock right aft, or from a set of special rollers (consisting of two vertical and one horizontal) placed in the same position. In the absence of a capstan the warp may be eased away from the bollards. For handling the dredge a purchase from the mizzen is useful, and with heavy patterns necessary.

In larger yachts the dredge may be towed direct from the trawling winch, the warp being led through the gallows or trawl-port to a strong davit or snatch-block on the port quarter, but the exact arrangement will vary with different vessels.

For shallow in-shore grounds, especially where very rough, manila warp is better than wire, as it is more easily handled and manœuvred if the dredge becomes fast.

In shooting, the dredge is slung overboard by the derrick or masthead tackle, and slowly lowered away. In very deep water the engines may be put at half speed, and the warp eased away more quickly. When towing from a davit on the port quarter, especially with twin-screw vessels, it is advisable to put the helm hard-a-starboard. In this case the dredge should be shot with the ship's head about four points to starboard of the direction in which it is intended to tow, so that the ship may at once be brought up on her course when the gear is clear away.

When a sufficient length has been paid out, the warp is

made fast by means of a rope-strop and rolling hitch;[1] if the dredge fouls, this strop should break. When using manila a few turns of the slack warp should be taken round the bollards, and when towing from the winch barrel the brakes should be left open if plenty of wire remains.

Tow dead slow, preferably with the tide, feeling the warp from time to time to make sure that the dredge is biting properly.

If the dredge hitches and the strop parts, stop the ship at once, and if it does not clear itself immediately, haul it up. Should it still remain fast, lead the warp forward and go astern, steaming slowly over the dredge.

The dredge is usually left on the bottom for from ten to thirty minutes; if longer time is given the net may fill right up and the strop on the bridle may part, involving the loss of the greater part of the contents.

The procedure in hauling is obvious. The ship is stopped, the rolling hitch is cast off, and the warp hauled by hand, capstan, or winch. In the latter case it is well to see that the warp is evenly spread across the breadth of the barrel; otherwise loose bights appear which later on will cause considerable annoyance.

With a considerable amount of warp out, it is allowable to go slowly and cautiously astern at the commencement of hauling, a careful watch, of course, being kept that the warp does not come foul of the propeller. If block and tackle are employed for getting the dredge inboard, it is advisable to keep the frame slung up, and if necessary lashed, until the contents of the bag have been emptied.

[1] It is sometimes difficult to make a rolling hitch hold on well-oiled wire-warp, especially when of small diameter; in such cases it will be found that a serving of trawl-twine or a canvas parcelling will materially assist. Alternatively, a nipper of the pattern shown in Figs. 194 and 195 may be used.

Trawling

Trawling is the best and easiest way of obtaining extensive samples of the bottom fauna, but the method can only be satisfactorily employed on smooth ground.

Three types of trawl are available for biological investigation—the beam trawl, Agassiz trawl, and otter trawl.

The Beam Trawl. In this pattern the net is kept open horizontally by a long beam of greenheart or oak, and vertically by a pair of iron runners or heads; Fig. 199 gives a good idea of the appearance of the frame.

Beam trawls may be used at practically any depth, but in very deep water they show a tendency to capsize, the beam dragging along the bottom, and the foot rope completely closing the net. In such cases the haul is naturally a complete failure. With a certain amount of experience in shooting this difficulty may be largely overcome; but the otter and Agassiz trawls will be found more efficient for work in greater depths than 300 fathoms.

The beam trawl collects a larger number of invertebrates than the otter trawl, but does not secure so many fish—active species of the latter are doubtless scared by the beam in its passage along the bottom.

Trawls of this pattern range from 6 to 50 feet in beam-length. Small makes, with a 6 or 8 feet beam, are easily handled from a rowing-boat or launch. The commercial beam trawl is usually from 40 to 50 feet in length; these sizes are, however, unwieldy, and the procedure in shooting and hauling is very complicated. Yachtsmen will find patterns with a 15 to 30 feet beam amply large enough. In these sizes the shooting and hauling does not present any considerable difficulty.

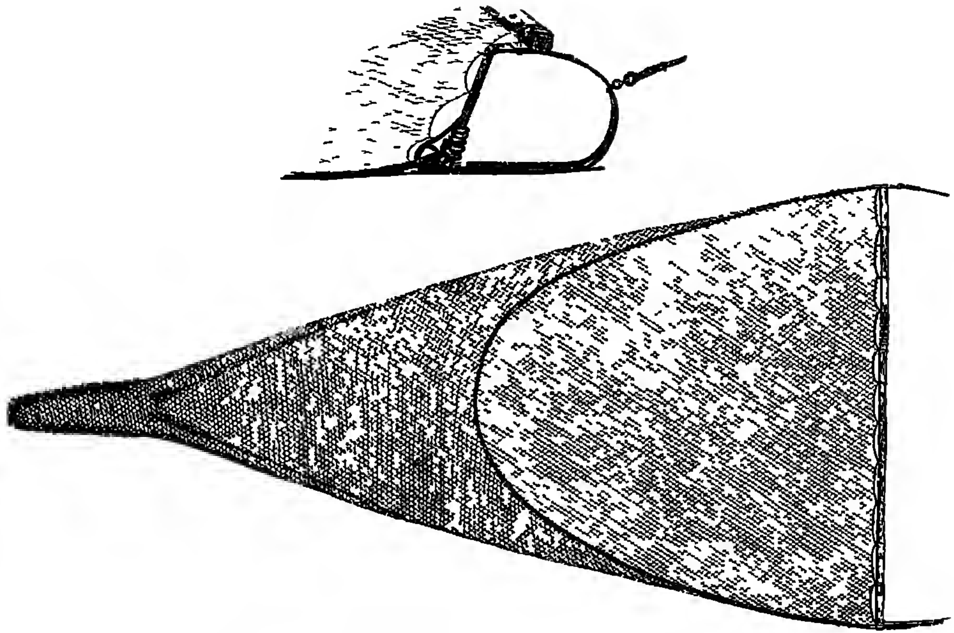


Fig 199 Beam Trawl

With enlarged view of the D-shaped head carrying the end of the beam, the span, and the foot rope

The beam trawl is towed by a pair of spans which are shackled to eyes in the front of the heads. Each span should be three and a half or four times the length of the beam, and as stout as the warp. The head rope of the net is as long as the beam, and is laced to it. The foot rope, to which the lower edge of the net is attached, is twice the length of the beam. The ends are securely lashed to the eyes at the back of the heads. As it is intended to scour the bottom, it is necessary to make the foot rope heavy; for medium-sized trawls 8-inch rope is recommended, weighted by the attachment of lengths of chain.

The net should be about one and a half times the length of the beam. It is made of hemp or manila twine of 2 to $2\frac{1}{2}$-inch mesh in the back and belly, and 1-inch double mesh in the cod end. The lower part of the cod end, which comes in contact with the ground, is protected from chafe by an extra piece of stout netting attached on the outside.

The trawl moves comparatively slowly over the sea bottom, and consequently fish which have entered the net frequently manage to swim out again and avoid capture. To obviate this, pockets are formed by stitching together the back and belly of the net at the sides, as indicated in Fig. 199, and by the inclusion of a 'flapper' or trap immediately below the pockets. This piece of netting, 3 to 4 feet in length, according to the size of the trawl, is made 50 meshes at top part and bated evenly on both sides to 25 meshes at bottom part. The meshes are of similar size to the meshes at that part of the net at which it is inserted. The 'flapper' should be put in its place before the pockets are laced up. The 50 mesh edge is sewn on the top or bating part of the net and the sides are then fastened on to the belly or lower part of the net, care being taken that

the flapper is not tighter than the net. The bottom part of the flapper is left unattached. The water passing down the net when the gear is being towed keeps the flapper open for the passage of the fish down into the cod-end. When the ship is stopped the flapper falls down, so that fish coming back along the net must go up into the pockets. The net is opened and closed behind by a running string through the meshes.

The 2- or $2\frac{1}{2}$-inch mesh is much too large to retain any small organisms. The whole net may be lined with sprat netting (1-inch mesh), or bags of the same material and of mosquito netting may be attached to the back, in the path of the swirl caused by the foot rope. The latter system has the advantage that the coarser part of the catch is kept in the trawl, while samples of the smaller animals are separately collected and saved from crushing.

Tow-nets with cane or iron rings and a long cheese-cloth bag may also be attached to the beam or to the net. If placed too far back, they frequently fill with sand or mud, and burst.

The very small makes of trawl, which are suited for use from rowing-boats or launches, are usually known as 'shrimp trawls'. In these the net is made of stout sprat meshing with a lining of mosquito net.

The length of warp required varies with the depth. The following table will give some indication of what is required:

In soundings	up to 50	fathoms	—3 times the depth.
,,	of 50–200	,,	—$2\frac{1}{2}$,, ,,
,,	of 200–500	,,	—2 ,, ,,
,,	of over 500	,,	—500 fathoms in excess of the depth.

Beam trawls may be towed from the warping-chock aft,

from a trawl-post, or from a wide-mouthed snatch-block [1] slung from a derrick or davit.

Shooting over the stern is much the most convenient, but the method can only be used with very small patterns. As a general rule, on all steam trawlers, it will be found best to shoot and haul the gear from the starboard side, the propeller on modern trawlers turning to starboard. The following is an outline of the procedure:

The trawl is laid on deck with the heels of the irons close to the rail, and with the net brought back over the beam. The spans are coiled down on deck, and the warp, after it has been passed through the trawl port or other fairlead, is shackled to them. It is best to use a separate shackle for each span. When these preparations are complete, way may be got on the ship, and the trawl shot with helm hard-a-port. The frame is lifted to the rail by hand or by tackle. The cod-end is put over the side first, followed by the heads and beam, the trawl drifting away on the port quarter as the spans uncoil. It is best to square the trawl by checking the after span, while the other is let run freely. This should be done while the net is still at the surface and can be seen. When the whole length of the spans has disappeared, the warp may be eased slowly away, and the ship brought up on her course. In most cases it will be necessary to trice the warp up to the after hawse pipe, to keep it clear of the propellers.

It is advisable to start shooting with the ship's head from four to eight points off the wind or tide, whichever is the stronger. The ship's course should be as straight as possible when shooting, the ship being brought slowly up to her course only when the gear has set on the bottom.

[1] A snatch-block for this purpose must be wide enough to allow the passage of the shackles connecting the warp and spans, and should have a deep V-shaped groove.

It is necessary to keep a steady strain on the warp and to check it repeatedly as it is being paid out. After each check the warp should be paid out gently at the beginning to prevent the beam and heads dropping and the net coming forward over the beam. Neglect of this precaution is the most frequent cause of a foul shot. When a sufficient length has been given, the warp is made fast (as in dredging) by means of a rope stop or by a nipper (p. 315).

The trawl is generally fished for from one and a half to two and a half hours. By holding the warp it is possible, in moderate depths, to feel the gear working its way along. With a little practice a useful estimate of the nature of the bottom can be formed by this means. If the trawl hitches and the stop parts, the net should be hauled at once. If it still remains fast, lead the warp to the bow, go astern and pull it backwards off the obstruction.

Hauling small beam trawls is not difficult. The warp is reeled in until the spans appear, and each span is separately hauled by hand until the beam and irons are got on board; the net may then be hauled in, foot rope first. This procedure cannot be applied to larger patterns (with beam more than 15 feet in length), for in these makes the weight is too great to admit of the spans being hauled by hand. The addition of a 'beam rope' is almost essential in such cases, and it is also advisable to step a stout davit with a snatch-block on the port quarter. The 'beam rope' is in reality a third span, used only in hauling. It is six feet longer than the spans, and is made fast by one end to the beam, close to the after head, and by the other to the trawl warp just above the shackle. When the spans appear through the fairlead, the beam rope (which is, of course, slack) is taken off, passed through the snatch-block on the port quarter, and led back to the capstan, or

to one of the small drums of the winch. Heave on the beam rope until the after span is slack and can be unshackled and taken from the sheave. Then heave away on the fore span and on the after beam rope until the trawl head appears. The quicker this operation is completed the better, as the net will hang almost up and down from the ship's side if there is no wind. Under these conditions the flapper does not operate and the more lively fish will tend to escape from the net. When the frame appears at the water's edge, one head after another may be lifted in by the masthead or derrick tackle. The net can then be hauled in over the beam, taking the foot rope first to avoid the loss of any of the contents.

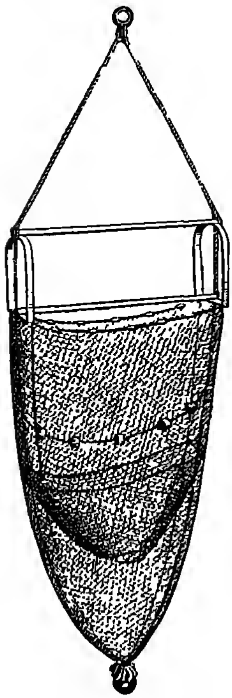


FIG. 200. Agassiz Trawl, *Blake* Pattern

The Agassiz Trawl. This is a small trawl useful for work in deep water. When a small trawl of the usual pattern is shot in deep water, it is liable to turn over, so that the beam lies on the ground and the net does not fish. In order to obviate this Professor Agassiz devised a trawl with two ground ropes and an iron frame, so arranged that the net would fish whichever way up the trawl fell on the bottom (Fig. 200). The shape of the frame is shown in the figure. The following dimensions are given by Tanner:

Beam: 11 ft.
Runners: length, 4 ft.; depth, 3 ft. 6 in.; width, 3 in.
Trawl net: length, 17 ft.; mesh, 1 in. to $\frac{1}{2}$ in.

For working in water over 100 fathoms in depth, it has been found advantageous to weight the frame considerably, and this may be conveniently done by winding chain around the iron beams. The net should be of 'shrimp' or 'sprat' mesh. The Agassiz trawl is more useful for catching invertebrates than for fish. Its disadvantages, as compared with beam and otter trawls, are that it is necessarily small and that fine-meshed nets cannot be attached to the back. The procedure in shooting and hauling does not differ in any essential way from that already detailed under 'Dredging' (pp. 331–3).

Agassiz trawls of small pattern (5 to 6 feet) may be operated easily over the stern.

The Otter Trawl. For work on small steamboats, especially where a winch or capstan of any kind is available, a small otter trawl is more handy to use than a beam trawl of equal spread. If it is desired to convert a beam trawl net into an otter net, the square of the beam net must be so cut that the net at this point will take the crescent-shaped curve of the head rope. The square of the beam net is straight to fit the beam. It would be preferable, however, to purchase a new otter square to fit the net. In the case of the otter trawl, two oblong boards, fitted with iron shoes—the otter boards—are used to keep the mouth of the net open. The mouth of the net in both beam and otter trawl has a heavy ground rope below, which drags along the sea bottom, and a head line above, which in the beam trawl is attached to the beam, but in the otter trawl is floated up in the water by means of corks or (in deep water) glass floats attached to it. These two ropes, the head line and the ground rope, are made fast at each end to the hinder ends of the oblong otter boards, which, when the net is working, stand on their lower iron-shod edges on the sea bottom.

The two otter boards act after the manner of kites which are 'flown' from the stern of the ship by means of two towing warps, one bearing away to starboard, the other to port. Each towing rope is fixed to its otter board by means of iron brackets or of four chains, in such a way that the point of attachment is behind the centre of the board, and the board therefore moves forward obliquely to the direction of tow. The two boards in this way keep a strain on the head line and ground rope, which increases with the speed at which the vessel is towing. It is probable that under normal working conditions the distance which the boards actually keep apart is about two-thirds the length of the head line of the trawl. The head line, being floated with cork or hollow glass balls, rises up in an arch between the two boards, and gives a much higher opening to the mouth of the net than is yielded by the beam trawl, in which the height of the opening is fixed by the height of the beam above the ground. This increase in the height of the opening of the mouth of the net constitutes one of the chief advantages of the otter trawl as a fishing instrument, since the take of round fishes, which swim a little above the actual bottom, is thereby much increased.

The size of the otter trawl usually worked on a steam trawler is as follows:

Length of head line, 96 to 105 ft.; length of ground rope 120 to 130 ft. The relative dimensions of head line and ground rope will depend on the type of square, top wing, and lower wing used in the trawl. The standard otter boards suitable for nets of the above dimensions are 10 ft. by 4 ft. 3 in., thickness 2½ in. Smaller nets may be used with these boards, but it is preferable to have lighter boards to suit such small nets. Size of mesh, measured diagonally with mesh taut, diminishes from 5½ inches in the square to 2¾ inches at cod-end.

The fine-meshed nets already mentioned in connexion with beam trawling may also be fitted to otter trawls.

On a commercial steam trawler two independent towing warps are used, one for each otter board, and special iron gallows are fixed to the vessel's side, fore and aft, for getting in the heavy boards. It is not necessary to give here the details of the method of shooting and hauling these heavy trawls, as this should not be attempted excepting with a specially fitted vessel and under expert direction.

The following instructions may be useful for working a small otter trawl from a small vessel, without special fittings. Such a trawl is most conveniently worked with two 'bridles' and a single towing warp, as in the case of a beam trawl. Each otter board should not be heavier than can be conveniently handled by one man.

The following dimensions apply to what is perhaps the largest otter trawl that can be conveniently worked in this way:

Square: 11 ft. long: 140 meshes down to 110; mesh 2 in.

Top wings: 17 ft. long; 36 meshes down to 6 at the board end; mesh 2 in.

Bottom wings: 31 ft. long; 25 meshes down to 28; mesh 2 in.

Batings: 110 meshes down to 36 meshes; length 20 ft. The pockets may be short or long, as desired, but must be started from the head of the 'flapper'.

Belly: Braided same as batings.

Cod-end: 56 meshes across, 6 ft. long. Mesh as desired.

Head rope: 44 ft., 7 ft. to be allowed for bosom and 18½ ft. for each top wing.

Groundrope: 57 ft. No bosom, but brought to an apex.

The circumference when rounded should be about 7 in.

Length of spans used: 50 ft. of $1\frac{1}{2}$ in. flexible wire. The main warp should not be too heavy as this has a tendency to pull the boards down.

Size of otter boards: 3 ft. 6 in. by 2 ft. 3 in.

A trawl of this pattern may be shot over the stern of the vessel. To prepare the trawl for shooting, attach the head line and ground rope to the two boards, shackle one bridle to each otter board, and then attach the other ends of the bridles to the towing warp by means of a freely working swivel. When the cod-end of the net has been tied, steam slowly ahead and pay the net overboard, starting with the cod-end. One man should be in charge of each otter board, and should stand on the outside of the bridles. When the net is trailing away all clear astern, the two boards are thrown overboard together, and a short length of the bridle is allowed to run out. The bridles are then checked for a moment to give the boards time to open the trawl. When this has happened, and the trawl is squared, the rest of the bridles are run out, being checked at intervals, until the towing warp is reached. The latter should be held for a moment, either by the brake of the winch, if one is being used, or round a bollard. The warp is then slowly paid out until the trawl reaches the bottom. The amount of warp required is the same as in the case of the beam trawl. The warp is made fast by a stopper of thin rope, which will part if the trawl comes fast.

When hauling the gear the vessel should not be stopped, but eased down a little until the trawl is off the bottom. The speed of the vessel should then be slightly increased in order that the trawl may be kept well astern while heaving in. The rate of hauling should be compatible with the strength of the towing gear. This operation tends

to carry all the livelier fish down into the cod-end. There is perhaps more art in retaining the live fish than in catching them, and if no lively fish are being got in the net, the speed must be accelerated to prevent their escape while the net is being hauled.

There should be fairleads on each quarter of the ship, so that when the spans come in they may be parted one on each quarter and the trawl hauled in the centre. The trawl will then be clear and the flapper working. The vessel should only be eased down when the boards are up at the fairleads. The ground rope is then hauled in. The boards should be left hanging outboard, and the trawl hauled in between them. The boards are in position for the next haul. If there is a heavy catch in the bag, a rope may be passed round it, and the bag hauled in with a tackle from mast or derrick.

General Gear

Before dealing in detail with the various kinds of line and net likely to be used by those for whom this work is intended, a few prefatory remarks upon the general subject may prove useful.

1. All lines and nets, of whatever material, should be oil-dressed or barked, not tarred.

2. Hooks, swivels, shackles, and other metal articles, if made of iron or steel, should be galvanized.

3. Many of the lines and nets described take up a lot of room when mounted ready for use; it is generally better in such cases to carry their component parts, and mount them as and when required.

4. All gear should be well dried after use before being stowed away.

5. Nets in particular constantly need mending, and any vessel carrying nets should also carry at least one person who can mend them.

6. Plenty of spare lines, hooks, snooding, twine, ropes, lead (pipe and wire), corks (or glass floats), and of anything else likely to be required for repairs or renewals, should always be carried.

7. And lastly, never despise native gear, however unpromising in appearance; for one thing, it is always possible to find some one locally who can make it fish efficiently; and, for another, it has probably stood the test of long use in practice. For exploring any waters in which a commercial fishery is carried on, the hiring or subsidizing of those who carry it on will probably, in the long run, prove the best way of securing fish.

LINES

Hand Lines may be used either with or without a rod. Quite apart from its sporting aspects, a rod possesses two advantages: (1) it holds the line clear of the boat, pier, or rock from which it is used; and (2) it enables lighter tackle to be employed than if a hand line is used.

For fuller information as to sea rods, reels, and lines, reference should be made to such books as the Badminton Library volume on sea fishing; but the following brief notes may prove useful:

The **rod** should be stiff and not too long, its metal parts made of phosphor-bronze or some other rust-proof metal. It must be remembered that the weight required to keep a line on the bottom in a tideway is considerable, and that a long rod is a nuisance in a boat, and in no way more efficient than a short one.

The **reel** should be large and of the ordinary Nottingham pattern, with an optional check. We do not know that anything is really better than a strong wooden reel with an easily fitting line drum, preferably with a rust-proof metal flange and back plate; the working parts

should be kept well greased and the line-drum fit easily, unless backed with metal; otherwise the wood will swell when saturated with sea-water, and the drum jam in the flange. The cost should not exceed 10*s*. or 12*s*.

For lines plaited and barked hemp is quite satisfactory and inexpensive, costing from 2*s*. 6*d*. to 4*s*. per 100 yards, according to weight; a twisted line is apt to kink, and should be avoided.

Traces and snoods may be of plain or twisted gut, horsehair, wire, hemp, or raw hide, according to the probable weight and biting powers of the prospective fish.

Swivels should always be used, whether for bottom fishing or trolling, between the running line and the trace.

Leads for trolling should be boat shaped or drain-pipe shaped—preferably the former if at all heavy. For bottom fishing a conical lead is as good as anything else; this should be attached to the trace by a snood of such strength as to break before the trace, if the lead gets jammed in a crevice among rocks or wreckage. It is advisable in bottom fishing to have a swivel between the trace and the lead-snood. A line rigged as in Fig. 201 permits the lead to be kept on the bottom at whatever depths the hooks are fishing, and render it easy to detect any inability on the lead's part to hold the line straight against tides or currents.

Spinning-baits, both natural and artificial, are numberless; we believe the best natural bait to be a strip of skin and flesh from the tail of some silvery and tough-skinned fish (e.g. a mackerel) or a small silvery fish used whole. Of the artificial baits, two standard and useful forms are (1) a piece of black, white, or red rubber tubing, and (2) a triangular or fish-tailed piece of bright metal, with its

edges turned so as to make it spin. Red worsted, also, has its merits, especially if used in combination with a bright metal spinner.

Fishes which swim and feed in shoals may often be caught by a 'jigger'; this is a piece of lead shaped like an ordinary sounding lead, and 6 inches long or less, armed according to fancy with bare hooks. The lead must be scraped bright before use, and is then worked rapidly up and down, so as to hook any fish attracted by curiosity or the prospect of its proving edible.

The above remarks apply generally to hand lines, but such lines must, of course, be considerably heavier and stouter than lines used with rods; also the use of plaited lines and swivels is not so necessary. When spinning with a hand-line, it is often more convenient to use several small leads than one large one (see Fig. 201). Hemp lines, 40 fathoms long, should cost from about 36*s.* to 74*s.* per dozen, according to weight.

Long lines, spillers, or bolters, are suitable for use in water down to 500 fathoms or more. They possess two great advantages: that they can be used on ground too patchy for trawling, and that they can be left to themselves while the vessel setting them is otherwise occupied; also one very serious disadvantage—that they require a great deal of bait.

The long line as ordinarily used by English fishermen for commercial purposes is 40 fathoms in length, and carries hooks on snoods of from 3 to 5 feet long, fastened on to the line at intervals of 1½ to 2 fathoms. Any number of such lines up to twenty dozen (which is the full outfit of a modern line-fishing vessel) are fastened together end to end, and fished in one string. The ends of the string are made fast to anchors or weights and their positions marked by buoys; and, in the case of a long string, further

anchors are added at the end of every sixteen lines, and their positions also marked by smaller buoys. Before setting, the lines must be carefully coiled in boxes or shallow baskets (each ordinarily holding eight lines), and the hooks baited and so arranged as to run out smoothly without fouling. Long lines should always be shot across a tide, and, where possible, hauled at slack water. No one who has not had considerable experience of long lines and their ways should ever attempt to set or haul them out of anything but a rowing-boat; and it is well to remember that if lines are set at low water or on a rising tide sufficient slack should be allowed on the buoy lines to prevent the buoys being drawn under the surface as the tide rises.

By regulating the distance from the buoys at

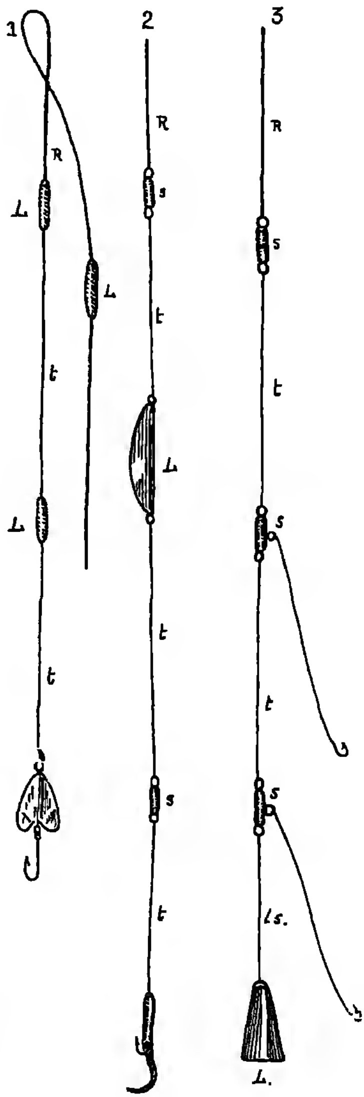


FIG. 201. Traces

1. Spinning trace suitable for use with a hand line with several small leads; 2. spinning trace for use with a rod or hand line; 3. trace for bottom fishing

R. Running line; *t*. trace; *s*. swivels; *l.s*., lead-snood; *L*. lead

which the lines are fastened to the buoy ropes, a long line may be set so as to fish at any desired distance from the bottom.

By the courtesy of a well-known east coast firm we are able to give the following estimates of the cost of long lines and gear. The detailed prices will give the necessary information as to the cost of unmounted lines and anything wanted for renewals. Mounted lines are not very easy to stow, and it might be advisable only to mount at least a part of the lines as and when wanted.

The prices given are for baskets of eight lines (320 fathoms in all); for ordinary use by yachtsmen or others fishing for scientific purposes, one or two baskets would probably be ample, and such a string would only require to be anchored and buoyed at the ends. The weights given are per line of 40 fathoms.

Halibut Fishing Gear	£	s.	d.
8 5½-pound 40 fathom lines at 74*s.* per dozen	2	10	0
160 No. 3 hooks at 27*s.* 6*d.* per 1,000		5	1½
160 60-in. cotton snoods at 50*s.* per 1,000		8	0
1 basket		12	6
4 pounds cork at 1*s.* per pound		4	0
Fixing lines		3	6
Per basket	£4	3	1½
Extra for swivel hooks per basket		6	6

Cod Fishing Gear	£	s.	d.
8 3-pound lines as above, at 48*s.* per dozen	1	12	0
160 No. 6 hooks, at 12*s.* per 1,000		2	5
160 cotton snoods as above		5	9
Basket, cork, and fixing, as above	1	0	0
Per basket	£3	0	2

HADDOCK AND WHITING FISHING GEAR	£	s.	d.
8 2-pound lines at 36s. per dozen	1	4	0
160 No. 15 hooks at 3s. 9d. per 1,000		0	8
160 snoods as above		3	0
Basket, cork, and fixing, as above	1	0	0
Per basket	£2	7	8

The following are required for a full outfit of 20 dozen lines:

		£	s.	d.
15 28-pound buoy anchors	at	0	12	6
15 60-fathom buoy ropes	"		18	0
2 buoy lights	"	1	2	6
12 small wooden buoys	"	17 to 20s.		
12 yards bunting	"		1	3

Plain hooks, unmounted, should cost from 3*s*. 9*d*. to 7*s*. 6*d*. per 1,000, according to size; and conger swivel hooks, unmounted, £2 5*s*. to £3 9*s*. per 1,000.

As will be seen, the only item which varies much in price in lines of various strength is the actual lines themselves, which increase in price according to their weight.

We believe that Scotch fishermen often use 60-fathom lines, five lines to a basket; these cost about £1 12*s*. 6*d*. per basket. We do not know the weight of such lines, which is, however, probably 3 to 4 pounds per line.

A commercial line fishery is carried on off the Portuguese coast in very deep water, and as the method employed may be found useful elsewhere, a brief description of the gear examined and described by Vaillant follows.

The line used consists of a hauling line, 650 to 700 fathoms long, and about ¼ in. in diameter, to which are fastened twenty to forty hook lines of the same material. Each hook line is about 16 fathoms long, and carries twenty cod-hooks on snoods 5 feet in length. The only weight used is made fast at the end of the last hook line (the first to be shot), and no buoy is used, the end of the

hauling line being made fast to the boat. As fished, at least the last ten or fifteen hook lines actually lie on the bottom (Fig. 202).

If it is desired to buoy a long line of the type above described in deep water, it would probably be prudent to use an empty 10-gallon water-breaker at least.

A handy method for working long lines with up to 50 yards of hooks, in a tideway, is to attach to one end a large empty bottle as a substitute for a weight or anchor. The bottle will float the line out from an anchored boat until it becomes taut, when the neck or mouth of the bottle will be dragged under and it will fill and act as a weight to keep the distal end of the line in position. The proximal end of the line can then be sunk with a weight. By this method the lines are, of course, set along, and not across, the tide, but good results may be obtained and the method can be used from a large or small vessel at anchor.

Trots, or small long lines, can be pegged down at low water and left for a tide and fished when uncovered again by the next low water. This method is used to a fair extent in the Thames estuary and in North Wales, where the flat foreshore lends itself to the method.

When long lining near the shore it is often advisable to have small corks on the snoods to float the baited hooks clear of crabs, which are liable to steal the bait. In the above two districts the old blackthorn hooks are said to give this effect.

NETS

1. **Hand nets.** Hand nets for use among rocks should have frames of one of the forms shown in Figs. 203, 204. The form of ring shown in Fig. 203 is best adapted for light nets for general use, or heavier nets for use on sand or mud; while that shown in Fig. 204 is more suited for heavy nets for use among rocks. The first of these could

be used with a net of either strong netting or stout mosquito net. Nets of either type, complete with handle, should cost from 4*s*. to 10*s*., according to size and make.

On sandy or muddy ground much larger nets can be

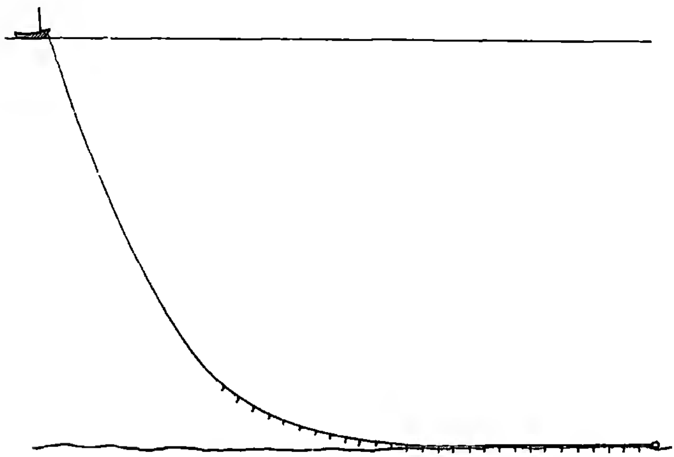


FIG. 202. Long Line, as used by Portuguese Fishermen

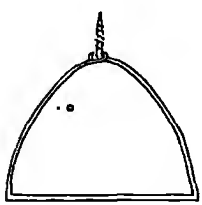


FIG. 203. Hand Net Frame

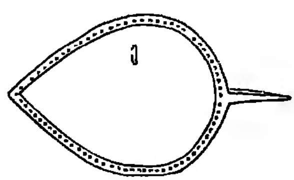


FIG. 204. Frame of Hand Net for use among Rocks

used, and many forms of such nets are locally used in different parts of the country for shrimping; the large shore nets used for this purpose on the Lincolnshire coast, which are about 10 feet in the beam and have 9-feet handles, cost about £1 10*s*. complete.

2. **Ring nets.** Ring nets are nets mounted on circular rings lowered into the water by means of a pole, and

baited. They are left stationary until a fish enters, and are then rapidly lifted above the surface. Small nets of this type, mounted on galvanized iron rings 24 to 36 inches in diameter, and costing with the necessary lines about 10*s.* to 15*s.* each, are commonly used for catching prawns, and are suitable for taking small fishes in the neighbourhood of rocks (see Fig. 205). A net of this pattern would pro-

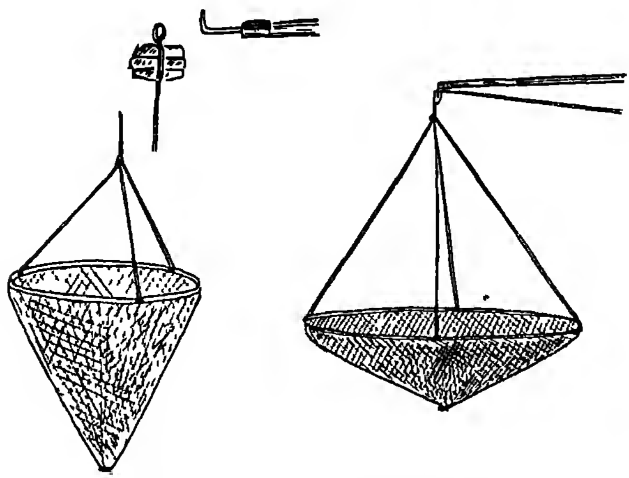


FIG. 205. Ring Nets

bably be improved by the addition of a second ring, which would enable it to collapse on the bottom without fouling. Much larger nets mounted on wooden or wire rings, and, where necessary, baited, are commonly used abroad for taking small fishes in shallow water; such a net, a fathom in diameter, ought not to cost more than 15*s.* or so, and larger nets in proportion.

3. **Fixed nets. Gill nets.** The simplest form of fixed net is the gill net, or splash net, which is simply a net of suitable mesh for the capture of the fish, mounted very slack on the head and ground ropes. The ends of the net are made fast to some fixed object or anchored, their

positions, where necessary, being marked by buoys. The head rope carries sufficient corks or glass floats to keep it at the surface, and the bottom rope must be sufficiently weighted to hold the bottom. A gill net will, of course, only catch such fish as are of a size to mesh themselves, and, to prove efficient, should be set so as to fish by night.

A well-known firm has kindly supplied the following quotation, which will serve as a guide to cost:

'Splash-net, 70 meshes deep, 2½ inch mesh, to hang 100 yards, 36s/9 ply, barked and mounted, corked and leaded, at 77*s*. 3*d*.'

A train of drift nets, such as that next mentioned, could be moored so as to fish as a gill net, if a properly leaded ground line were fastened along its foot; but a drift net is ordinarily rather deep for use as a gill net, and is not always mounted along the foot.

The pollen fishers of Lough Neagh use gill nets (locally termed 'trammels') made of exceedingly light but strong linen thread; these nets are made at Lisburne, and possess the advantage over either hemp or cotton nets of stowing into much smaller space and wearing better. In cases where economy of room is important, it might be well worth while to have nets made of linen thread.

A large meshed set net is used for the capture of Palinurus, the Rock Lobster, in Cornwall. Here the net is 6 to 10 meshes deep and about 30 fathoms long, each mesh being about 1 foot in diagonal measurement. These are locally known as crab nets.

Drift nets (Fig. 206) are similar in their operations to gill nets, but are constructed to fish at or near the surface; they are not moored, but drift on the tide. For commercial purposes a train of drift nets, often far over a mile in length, is used; these nets are fastened end to end, and carry sufficient cork on the head ropes to keep them upright in the water, but not necessarily to keep the head

rope at the surface. At frequent intervals buoys of wood or canvas are fastened to the head rope, and the length of the buoy lines regulates the depth at which the nets fish. Drift nets may or may not be mounted on a foot rope; in shallow water where the ground is rough, the absence of such a mounting may prevent damage to the nets from hitching in rocks. A train of nets is, however, made fast at fairly frequent intervals to a stout hauling warp, which serves the double purpose of preventing nets being lost if the head rope is cut by a passing steamship, and of taking a part of the strain during the process of hauling.

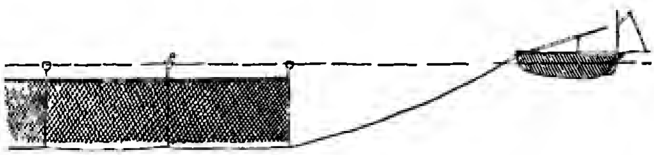


FIG. 206. Part of a Train of Drift Nets (Diagrammatic)

We are informed by well-known makers that a short train of drift nets—say, 400 yards long, hanging about 7 yards deep—mounted on two lines on top and bottom, and corked on top, should cost about £44. In the case of such a short train a separate hauling rope could probably be safely dispensed with, but the above estimate does not include buoys or buoy lines.

To prove effective, drift nets must be fished by night, or, if by day, only in thick or discoloured water; fishermen, as the result of long experience, generally believe that the greatest number of fish enter the nets just about dusk and dawn. Drift nets should be shot from a vessel moving with the wind; when the nets are all overboard, a greater or less length of hauling warp (according to wind, size of vessel, and length of train of nets) is paid out, and the vessel brought up head to wind; masts are unstepped, and

all gear likely to offer resistance to the wind stowed, and both vessel and nets drift on the tide, the weight of the vessel tending to keep the hauling rope taut, and so to prevent the nets fouling. In motor or steam vessels the nets are generally shot over the starboard quarter. In inshore waters small fleets of drift nets are often allowed to drift unattached to any boat at all. A considerable sprat and inshore herring fishery of this type is carried on along the east coast.

The trammel [1] is set in the same way as a gill net, but its action is different; it is peculiar in being made up of three distinct nets or sets of meshes fastened together at the head, foot, and ends. The two outer nets are of large mesh, mounted taut on the head and ground ropes, and set so that the meshes exactly correspond. The middle net is twice as long and twice as deep as the two outer ones, has a very much smaller mesh, and is mounted very slack on the head rope. The result of this is that a fish, coming in either direction, on striking the net, carries a portion of the middle net through the large mesh of the outer wall, and is thus trapped and held. For commercial purposes, the walls of a trammel are ordinarily some 40 to 50 fathoms long, with a 9 or 10-inch mesh between knots, and a depth of twelve to twenty meshes; the middle net is 80 or 100 fathoms long, but set on a head rope of the same length as the walls, and has a mesh of about 2 inches, and a depth of some 50 or 60 meshes. The length and depth of the net and size of meshes must be varied according to the probable size of the prospective fish.

A Scotch firm of net manufacturers has kindly supplied the following estimate:

'Trammel, 9 ft. deep, barked and mounted on 15-thread rope on bottom, and 9-thread rope on top, corked and leaded ready for

[1] The term 'trammel' is commonly applied to gill nets in Ireland.

fishing, dimensions: two outside pieces, 20 meshes deep, 9-in. mesh, 21-ply cotton: inside piece, 120 meshes deep, 2¼-in. mesh, 36/9 ply cotton, £8 10*s*. 3*d*.'

Like other fixed nets, trammels should be used by night; they are not easy to dry properly, and consequently liable to rot if not very carefully treated. Moreover, cleaning a trammel after use on weedy or crab-frequented ground is a task calculated to try the patience of Job himself.

A trammel used as a drift net is very effective. In at least one fishery district (Connah's Quay) trammels are, or were, not allowed to be fixed to the bottom and therefore have to be employed in this manner.

In ordering any fixed net, the maker should be told the purpose for which it is intended, as a clue to the size of mesh required; probably the mesh could be best described by giving the size of the fish anticipated—e.g. 'east coast herring', 'spring mackerel', or 'pollack'.

Seines. A seine, or sean, is a long, comparatively shallow net, which is so shot that it can be drawn over a certain area of ground or water in such manner as to capture anything within that area. A seine net may be used either from the shore or in the open sea. In the latter case one or two boats may be used.

The head rope should carry sufficient cork or glass balls to float the net itself, but the ground rope must be so weighted as to hold the bottom during the whole of the hauling operations. When fishing in deeper water than the width of the net, the corks will necessarily be pulled below the surface during the first part of the haul.

Judgement must be used as to the length of rope payed out in accordance with the strength of current, the shelving nature of the beach, and the power available for hauling the net ashore.

The boat is rowed out from the shore in a direction

across the current, and the person in charge of the shore end of the rope must proceed slowly along the shore, keeping the line taut and across the current. When the

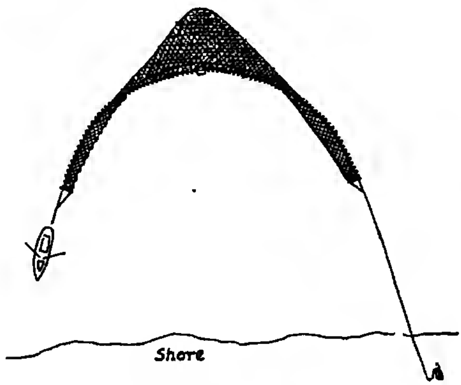


FIG. 207. Seine Net

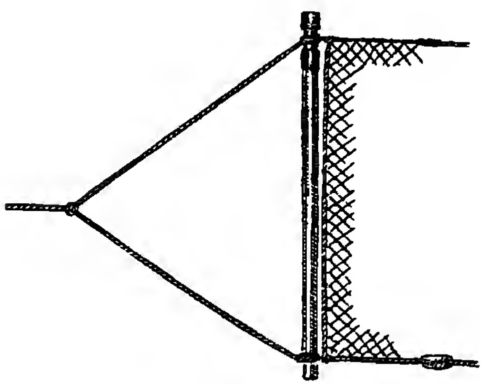


FIG. 208. End of a Seine Net

shore line is almost completely payed out, the boat is brought round in line with the current and the net shot. The boat must then be brought round quickly just before the net is all out and rowed in the direction of the shore. The line is brought ashore and hauling operations begun. The lines should be marked so that they may be hauled

evenly even when the net is out of sight. The ropes should be hauled so that the net is kept at its maximum breadth, which gradually diminishes as the net comes in. At the finish of the haul, and when the net is being hauled ashore, care must be taken always to keep the ground rope on the bottom until the net is finally hauled out of the water. A tuck seine only differs from a seine in having a bunt or bag (analogous to the cod-end of a trawl) in its centre, which collects the fish and prevents their escape.

Seines and tuck seines are principally of use for catching fish on a smooth strand, particularly on a gradually shelving beach or in an estuary. They are most efficient if fished at night or at low springs. The best time of the tide is at slack water on either tide.

For commercial purposes seine nets which have no bunt are frequently used, but such nets require very careful handling, and are not suitable for the inexperienced. On the other hand, a tuck seine of moderate size is not at all a difficult net to work; the best net of this description known to us is that used by the Saltash fishermen in the Tamar, briefly described below. Such a net can be easily worked by two men with a small rowing-boat, and may be procured locally for about £6, including poles and hauling warps.

A tuck seine should be set somewhat slack on the head and ground ropes, which are each about 48 yds. long; each wing is 20 yds. long and about $2\frac{1}{2}$ yds. deep, and the mesh decreases from the pole to the bunt, the depth of the net remaining the same, or increasing very slightly (e. g. the wings may be set up at $2\frac{1}{2}$-in. mesh 60 deep, and made down to $1\frac{3}{4}$-in. mesh 90 deep). The bunt is about 6 yds. long, about 300 meshes round where it joins the wings, and of the same mesh as their inner ends, tapering nearly to a point without any great reduction in

the mesh. The head and ground ropes are hitched round the poles (which are each 6 ft. long) a short distance beyond the ends of the wings, and are then carried out and joined round an eye to which the hauling warp is shackled. The mesh must, of course, depend upon the size of fish which it is desired to capture.

Danish Seine Net or 'Snurrevaad'.—The 'snurrevaad' is a type of seine net which has been employed in Denmark for many years, but has been introduced into the British Fisheries only in recent years. Owing to its construction of very light material it is specially suitable for motor-boats and drifters. This method of fishing is carried on mainly during the summer months, and the best grounds for fishing are those with a smooth, sandy bottom, where the water is comparatively shallow. Two different types of nets are employed, namely the plaice seine and the haddock seine, the latter having shorter wings, a longer bag, smaller meshes, and a 'flapper'.

Plaice Seine. Ground rope: 5 ft. longer than head rope.

Wings: each 100 ft. long; 85 meshes to 40; mesh 4½ in.

Belly and batings and cod-end: 30 ft. long; 210 meshes to 70 at the cod line; 15 ft. 4-in. mesh, 15 ft. 3½-in. mesh.

Haddock Seine. Wings: each 80 ft. long; 100 meshes to 42; 4-in. mesh.

100 bosom meshes on foot rope and head line.

The 100 meshes of each wing joins the 150 meshes on either side of the belly.

Belly, batings, and cod-ends: 50 ft. long; 100 meshes at cod line.

10 ft. with 3½-in. mesh; 20 ft. with 2¾-in. mesh; 20 ft. with 2½-in. mesh.

The net is made of cotton, the cod-end having double cotton. The head rope and foot rope are of hemp 1½ in.

circ. The head line is provided with either cork floats or glass balls to keep the mouth of the net open, and the foot rope is weighted with lead, the sinkers being slightly heavier in the bosom. The net should be so mounted that the net is dragged lightly over the bottom. When fishing for flat-fish the ground rope may be loaded with short lengths of chain, so that the net may be dragged steadily over the bottom.

Before shooting the net a 'dan' is anchored in a suitable position. The end of the first warp is attached to the anchored buoy, and the ship then steams two points off the tide, paying out the warp, which is allowed to run freely. After paying out about 600 fathoms or more, according to depth, the ship is turned so that the last 100 fathoms of warp, the net, and a further 100 fathoms of warp, are laid across the tide. The ship is then turned and steams up towards her mooring buoy, paying out sufficient warp to prevent any drag on the net and to reach the buoy. The vessel is then made fast to the buoy, and both warps are hauled together by means of a special winch. The warps remaining on the bottom during the hauling operations keep the net open until it is almost alongside the ship.

THE MID-WATER OTTER NET

Although the 'Young-Fish Net', or mid-water otter net, originally designed by Professor Petersen of Copenhagen, is in reality little more than a very large and special tow-net, it may be conveniently included here as being the only net hitherto designed which is suitable for the capture of small fishes at the surface or in mid water. The net itself is made of a coarse-meshed material, which is sufficiently fine to retain small fishes and sufficiently strong to stand the strain of fishing. As ordinarily constructed, it has a rectangular mouth about 7 ft. wide by 5 ft. deep,

a length of about 21 ft., and tapers to an opening of about 2 ft. in circumference at the cod-end. The sides of the mouth are laced on to stout wooden poles, and the net is kept open while fishing by otter boards (see p. 341), which are joined by ropes to the head and foot of the poles.

The material of which the Danish nets are made is woven of coarse hemp thread and has about 14 meshes to the inch. The material is known as 'stramin', and can only be obtained in Denmark, costing about 4*s*. a metre.

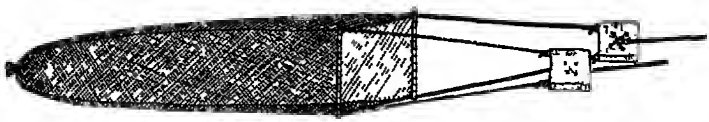


FIG. 209. Petersen's Yngel-Trawl or Young-Fish Net

In fishing the net in deep water a heavy lead weight (ordinarily about 40 lb.) should be attached to the shackle fastening the spans to the hauling warp, and the otter boards must always be well weighted. The net may be shot from a single block with a little way on the vessel, and the otter boards lowered together, as, if properly weighted, they spread as soon as they are in the water.

Surface hauls should only be of short duration (e. g. fifteen minutes), as the net soon becomes choked with jelly-fish, salps, and the like, but in deep water hauls of less than an hour's duration cannot be expected to give much result. The net may be fished actually on or just clear of the bottom with good effect, but is very liable to injury if so fished.

If the same sized net used in this young fish trawl is mounted on an iron ring 2 m. in diameter, the boards can be dispensed with, and the net becomes very much easier to handle. The fishing capacity of this *ring-trawl* appears also to be quite as good as that of the net with otter boards.

PETERSEN GRAB

For the capture of worms, mollusca, and other animals living in the sea bottom, the bottom sampler known as the Petersen grab will be found very efficient if the power is available with which to work it. In general principle it acts in the same manner as the instrument used for dredging harbours or coaling ships. It brings up a good sample

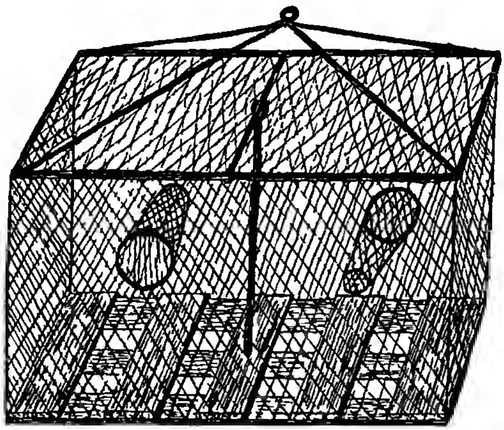


FIG. 210 Collapsible Pot

of the bottom and the animals contained therein, and by its means animals, practically unattainable in any other way, can be taken. The apparatus, small size, weighs about half a hundredweight and costs about £30.

MISCELLANEOUS GEAR

Some fishes may be taken in crab or lobster pots suitably baited; probably the pots made of netting stretched over a metal or wood frame are better than those made entirely of osier.

A very convenient form, owing to the small space required for stowing it, is 'Peet's collapsible pot', the inven-

tion of a Whitehaven fisherman. It is illustrated in Fig. 210, and can be collapsed by removing the central strut.

Narrow and shallow creeks and channels may be fished by stretching a short gill net across them, and beating the water up towards it by wading in line with poles and splashing, or by dragging another net towards the fixed one.

X

FISHES

BY L. W. BYRNE

THERE are perhaps no living creatures which are more constantly brought to the attention of any person living on or near the sea than fishes, and yet there are not many groups whose habits and life-histories require more elucidation. Our knowledge of the growth and appearance of the young stages of even the commonest fishes of our own coasts has only been acquired within the last quarter of a century, and there are still species of whose breeding habits we are almost completely ignorant.

The persons for whom the present work is primarily intended may well have neither the opportunity nor the leisure to make exhaustive collections of specimens of fish, and our endeavour in the following pages is to direct attention to the class of observation that is likely to prove both interesting to the actual observer and useful either to the student of ichthyology or the practical fisherman.

Whatever the nature of the observation made, it is obviously of the first importance that the species of fish under observation should be correctly identified. To insure this, the safest plan is to preserve at least one specimen of such fish; but as any individual, however carefully preserved, is almost certain to undergo some post-mortem change of shape, and to lose the colours which adorned it in life, it is well, wherever possible, to take careful measurements, and make a sketch or note of the colours of the living or fresh animal. This is important, both in the case of colours, which frequently differ in the two sexes, and are nearly always subject to change at or shortly after death; and also in the case of delicate scales or fins, which are easily damaged.

Fig. 211 is intended to show the more salient points in the external topography of a fish, and the names by which they are commonly referred to in descriptive literature.

In taking the measurements of a fish, the accepted method is, not to follow the contours of the body, but to measure between perpendiculars, as shown in Fig. 212. The measurements ordinarily used in descriptions are those there shown, and, in addition, the distance between the eyes (measured by callipers or compasses between their bony orbits), and sometimes the greatest breadth of the head and body respectively. These measurements should be taken in centimetres and millimetres.

In addition to these measurements it is usual in the case of Teleostean fishes to count the number of rays in the dorsal and anal fins, discriminating between spines and soft rays, and the number of scales (when present) in a longitudinal series along the body above the lateral line, and in a transverse series from the back to the belly at the deepest part of the body.

In cases where there is more than one dorsal or anal fin, the number of such fins and the number of rays in each should be noted.

When from lack of time it is impossible to take the actual measurements of a series of specimens, their proportions should be noted (for example, eye goes five and a half times into head; head, six times into length without caudal fin, &c.); but even where it is only possible to note proportions in this manner, the total length of the specimen examined should always be recorded.

It is well to adopt some regular method of recording measurements in tabular form, any particular notes as to maturity, coloration, shape of fins, or other matters requiring note, being added at the foot of the list of measurements. The general practice is to indicate spinous fin-rays

by Roman figures, and soft fin-rays by Arabic numerals, and to insert a comma to mark a break in the continuity of a fin.

The table below of actual measurements and notes, as taken, should help to explain this.

SPECIES—G. MINUTUS; LOCALITY—INISBOFIN, AUGUST.

	1	2	3	4	5	6
Sex	♀	♀	♀	♀	♂	♂
Length (mm.)	72	65	65	64	63	58
Length with caudal	82	76	75·5	73	73	69
Head	16	16	15	15	15	14
Snout	4·5	4	4	4	4	4
Eye	4·5	4·5	4	4	4	4
Depth of body	12	10	10	9	9	9
Depth of caudal peduncle	5	5	5	5	5	4·5
Fin rays, dorsal	vi, 12	vi, 12	vi, 12	vi, 12	vi, 12	vi, 11
„ anal	12	12	12	12	12	12
Scales, long: series	64	64	65	62	62	66
„ transverse: series	17	16	18	16	16	17

All spent: (5) with some small ripe spermatozoa. Very slight traces of dark pigment on the undersides of ♂♂, spot on spinous dorsal slightly more intense in ♂♂. Height and shape of soft dorsal similar in both sexes.

Before dealing in detail with the special points to which we think the attention of an observer of fishes should be directed, it seems convenient to commence with a very brief account of the best methods of searching for fishes in localities of different natures, even if the information may have been given in the previous chapter.

To begin at the very margin of the sea, numerous fishes are to be found between tide-marks on rocky shores. In searching a locality of this nature, it is, as a rule, not much use beginning far above half-tide mark, unless large and sheltered rock-pools are to be found at higher levels. The site selected for examination should be as sheltered as possible, and, even on bare and exposed coasts, gullies

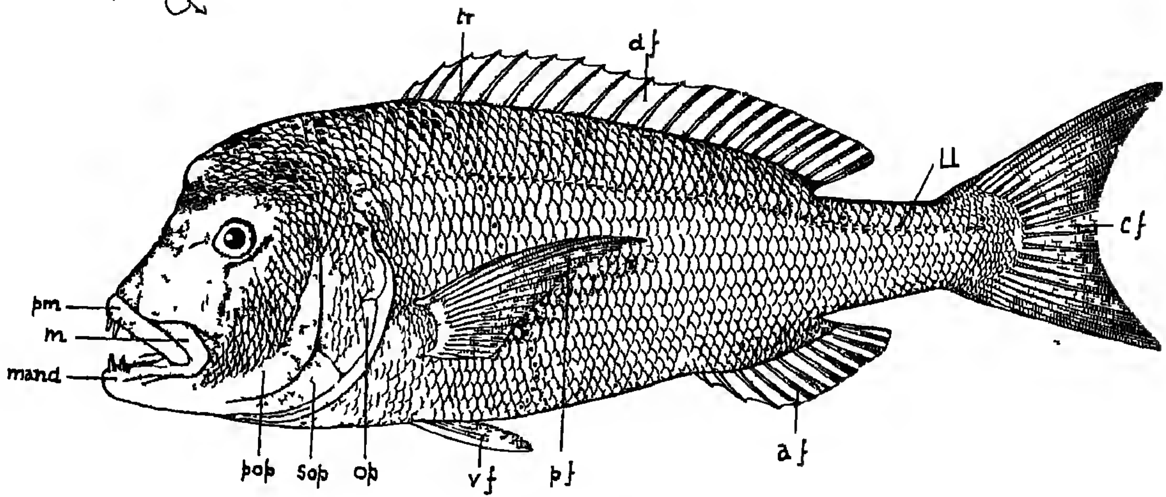


FIG 211 Descriptive Topography of a Fish

af	Anal fin	*mand*	Mandible	*pop*	Preoperculum
cf	Caudal fin	*op*	Operculum	*sop*	Suboperculum
df	Dorsal fin	*pf*	Pectoral fin	*tr*	Transverse series of scales
ll	Lateral line	*pm*	Premaxilla	*vf*	Ventral fin
m	Maxilla				

and crevices among the rocks may often be found in which there is a considerable growth of weed, of sponges, and of other encrusting animal growths sufficient to shelter the small animals upon which fishes feed, as well as the fishes themselves.

It must be remembered that many shore fishes normally spend the period of low water in very small and shallow puddles, or even on a patch of bare sand or fine gravel, provided the spot is sufficiently protected from the sun by sheltering rocks or boulders carrying a growth of weed or encrusting animals. Stones and boulders, of the size of a man's fist, or larger, should be lifted, even when loosely packed to the depth of 1 or 2 ft., and the small pools or wet hollows under them examined, from half-tide mark downwards; hollows or pools under the shelter of growing weed or rocky ledges should also be searched with a hand net (see p. 353).

Larger rock-pools can be similarly searched by dint of wading, or, if too deep for this, by dangling a bait upon a small hook in front of likely looking hollows and crevices, the fisherman being careful to keep himself out of sight.

The roots of such seaweeds as have large tangled and bulbous roots will often repay examination, and are not infrequently selected as nesting sites by some fishes.

On **sandy** and **muddy shores** and **estuaries** the best spots for searching are the pools and runnels left by the receding tide, preferably such as from their situation alter little in depth and position from tide to tide. A hand net can be used in such localities, as can any form of shrimp net.

Below **tide-marks** and in shallow water, sandy and muddy ground can be efficiently searched with almost any form of shrimp net or shrimp trawl (see p. 337), or by a tuck net or hauling seine (see p. 360), according to the

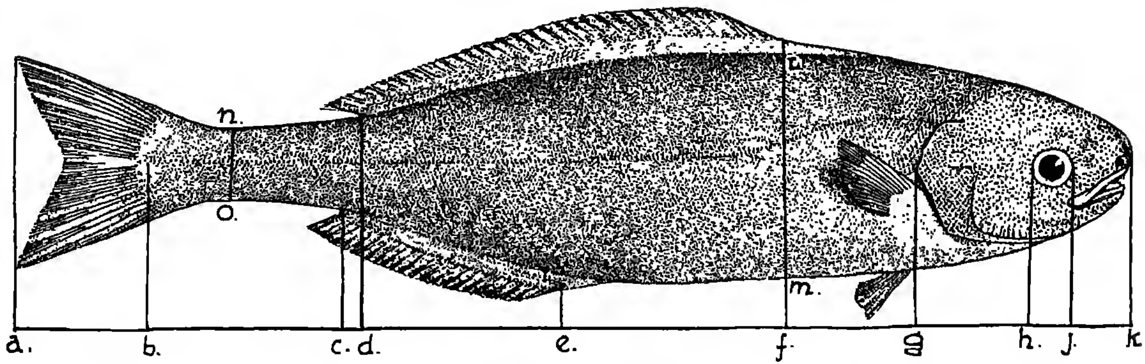


FIG. 212. Descriptive Measurements of a Fish

a k.	Total length	*h j.*	Horizontal diameter of eye	*d f.*	Length of base of dorsal fin
b k.	Length without caudal fin	*f k.*	Length to origin of dorsal fin	*c e.*	Length of base of anal fin
g k.	Length of head	*e k.*	Length to origin of anal fin	*l m.*	Greatest depth of body
i k.	Length of snout	*b c.*	Length of caudal peduncle	*n o.*	Depth of caudal peduncle

depth; especial attention should be paid to beds of sea grass or weed, and to the immediate neighbourhood of ledges or patches of rock.

As the water deepens, recourse must be had to larger and heavier trawls (see pp. 334–45), which can be used on any ground not so uneven or rough as to prevent the ground rope gripping the bottom or to tear the net.

The weed-covered sides of piers and quay-walls will often prove excellent hunting-grounds if carefully searched with a hand net, or, in deeper water, by fishing close to them with fine tackle.

Rocky ground, ground too rough for trawling, and ground encumbered with wreckage, when below tide-marks, can only really be fished by hook and line. Native fishermen have usually learnt by long experience the best localities for line-fishing, and, in the absence of such guidance as they can afford, experiment alone can discover them. In the absence of local guidance as to baits, almost any large marine worm, mussels, or similar soft-fleshed shell-fish, the tails of hermit crabs, cuttle-fish cut into strips, or pieces of almost any fish—preferably such as contain a quantity of fat or oil—may be tried as baits.

Trammels and gill nets (see pp. 357, 354) are most efficiently used when set from the end of a reef of rocks where there is a rapid drop into deeper water.

The surface waters of the sea, whether inshore or in mid-ocean, should be fished by tow nets of comparatively large mesh at various depths (see p. 230), or by a 'young-fish net' (see p. 362), and to such localities the general remarks under the head of 'Tow Netting' are applicable. We know of no net really well adapted for taking the larger fishes of the surface waters or middle depths of the ocean.

At the actual surface a line with a spinning or trolling

bait can, of course, be used, and fishes are often found accompanying floating weed, wreckage, or large pelagic jelly-fishes.

Sometimes in calm weather a powerful light displayed over the ship's side attracts surface fishes, or, at least, makes them visible, and renders their capture with a dip or hand net possible.

In very deep water, down to about 3,000 fathoms, fishing may be conducted on the bottom either by means of a suitable trawl or dredge (see Chapter IX), or by long lines. Various forms of fish trap have been tried for fishing under such circumstances, but we are unaware of any such implement suitable for use by a vessel which does not carry a special equipment for deep-sea exploration.

Habits of Fishes

From the nature of their haunts it is not always easy to observe the habits of fishes in a wild state, but such matters as the nature of their food (ascertained by examination of the contents of their bellies), breeding season (tested by the development of roe or milt), and seasonal movements (as shown by their presence or absence in a particular locality at different times of year), should ordinarily be susceptible of ascertainment.

Other matters as to which information may sometimes be obtained are the nature of their haunts, whether at the surface or the bottom, on mud, sand, gravel, or rough ground, or among coral or rocks; the depth at which they are ordinarily found; and their predilection for salt, brackish, hot, cold, clean, or turbid water. At times such observations may necessitate the use of special gear (such as closing tow-nets), the taking of temperatures, or the testing of the salinity of any particular part of the sea; but the necessary information may often be obtained by the

use of simple sounding apparatus or even by ocular observation, while the statements of fishermen on such subjects are often both precise and accurate.

In places where the usual commercial fisheries are confined to inshore waters, and especially where their main object is to supply a local market, seasonal changes of venue and gear in native fishing operations, and of the kinds of fish brought to market, will often afford useful information.

Among shore fishes, the observations of breeding habits, to which allusion will be made later, is often both easy and interesting; and, at whatever depth a fish is captured, sexual differences of form or colour may be observed and noted by comparison of examples of both sexes, especially such as are shown by their roes or milt to be approaching the breeding season.

As an observation of such sexual differences is of the greatest importance to systematists, and can best be made in a living or fresh example, we may briefly point out the details which demand attention:

1. The presence of external copulatory appendages (as in sharks, rays, and chimaeroids) or of a prominent genital papilla.

2. Outgrowths of the scales or dermal covering, and differences in the teeth.

3. Differences in the profile of the head and back.

4. Elongated fin rays (especially of the dorsal and anal fins).

5. Thickening of the rays of the pectoral, ventral, or anal fins.

6. Differences in size.

7. Differences in coloration.

8. Differences in the arrangement of the luminous organs of oceanic fishes.

Attention should further be paid to the size at which each sex commences breeding, to the comparative abundance of specimens of the two sexes, and to the permanent or transitory nature of the sexual differences observed.

In many fishes colour changes may occur with startling rapidity, especially under the influences of shock or excitement. Such changes are difficult to observe except in captive examples, but may often be noticed if a fish is kept in a bucket on deck for a short time after capture.

The courtship of shore fishes may sometimes be observed in the pools in which they live or in a tank in which examples of both sexes are kept in captivity. In the case of the male, courtship is often attended with more or less rapid colour changes.

Eggs

Sharks and rays and allied fishes are either viviparous or else lay large eggs enclosed in horny capsules or 'purses' (Fig. 213); the dissection of pregnant females will often serve, in viviparous species, to show how many young are born in one litter; or, in oviparous species, to connect an egg capsule with the parent fish.

Teleostean fishes, although sometimes viviparous, usually produce a comparatively large number of small eggs, examples of which are shown in Fig. 215.

These eggs may be either 'pelagic'—that is, buoyant and floating in the water at whatever depth—or 'demersal'—that is, attached to some object, or lying among gravel or debris at the bottom.

The pelagic eggs of different species of fish vary from about 0·5 to 2 mm. in diameter, while demersal eggs are commonly somewhat larger, and are seldom less than about 1·5 mm. in diameter. Their diameter is most easily measured by putting them under a microscope of low

power, with an eyepiece ruled in squares of about 0·05 mm. value with the objective employed.

It should be remembered that the eggs of teleostean fishes are very readily fertilized artificially, if ripe examples of both sexes are forthcoming for the purpose. To effect artificial fertilization, all that is necessary is gently to stroke the belly of the fish from in front backwards until eggs or milt are extruded, and to catch these products on extrusion in a jar containing a little sea-water. It is no use trying to fertilize eggs unless naturally extruded by the female; but, in the case of males, milt approaching ripeness and obtained by dissection is sometimes sufficient for the purpose.

If a ripe female is obtainable but no male can be found, the eggs should be allowed to remain in sea-water for some hours after extrusion before being examined, so as to allow them to attain as far as possible their normal size after distension on contact with water.

Pelagic eggs, if not obtained direct from the parent and artificially fertilized, may very often be found among the gatherings of tow-nets. When obtained, they may be kept alive for a long period, and their development and hatching watched if they are kept in jars of clean sea-water of the proper salinity and temperature, occasionally changed. They are, however, very susceptible to sudden changes of salinity or temperature, and care must be taken not suddenly to change them from the relatively chilly and saline water of the open sea to the warmer and fresher water of a harbour; such errors and consequent disappointment can generally be guarded against by the use of a little care.

Demersal eggs are occasionally laid either loose or in adhering masses on the sea bottom, and left to hatch (as in the case of the herring); but are more commonly laid

either in masses or in an even layer, and cared for by the parent (usually the male) during the process of incubation. Many shore fishes, and some normally living in deeper water, construct nests, or guard or carry about their eggs during development.

Instances of the latter habit may be found in the pipe fishes and sea-horses, in which the male carries the eggs

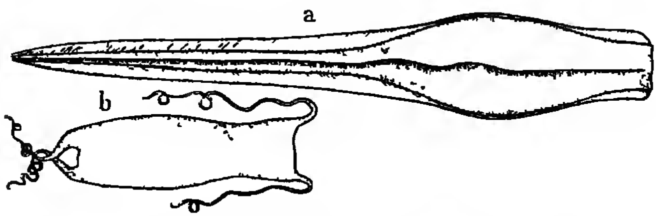


FIG. 213. Horny Egg Capsule of (*a*) Chimaera, (*b*) Scyllium

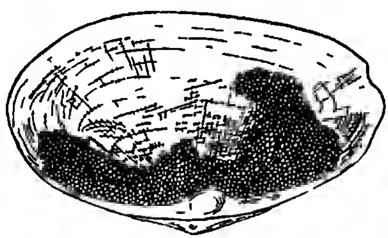


FIG 214 Demersal Ova of a Shore Fish (Gobius minutus) in an Empty Shell

in a pouch or groove in the belly; and in some catfishes and perciform fishes, in which they are carried in the mouth or throat.

The line between what may be termed nest-building and the mere guarding the eggs is not very easy to draw.

In some cases (e. g. sticklebacks and some wrasses) a more or less elaborate nest of seaweed or other material is formed; in others (Lepadogaster and some blennies and gobies) an empty shell (Fig. 214) or the hollow bulbous

root of a seaweed is selected; again, the fish may overturn a shell, so as to form a hollow beneath it, and then conceal the chamber so formed with a covering of sand, or may be contented with a crevice in a rock or overhanging stone. We have known the hollow at the foot of a recording thermometer lifted daily from the harbour where it lay, tenanted by a small goby and his brood. From such examples as these the step to those cases in which the eggs are laid in a more or less exposed situation, and merely guarded by the male parent, is a very short one.

When shore collecting, or dredging, or trawling in shallow water, it is, consequently, well carefully to examine crannies in rocks, the undersides of stones and old shells, tins, old bottles, and any other likely sites. Very frequently the secret is disclosed by the discovery of the dutiful parent, and by his reluctance to leave his charge. Often enough the assiduity of the male in defending his charge may be observed in the pool in which he is found; but matters are facilitated by removing him and his brood into a tank or large shallow dish.

Larvae

The newly hatched larvae of fishes are, like pelagic eggs, commonly taken in tow-nets, and careful observation is required to enable these to be connected with specimens hatched in captivity from the eggs of known parents, or with the older stages which gradually lead to the attainment of the form and characteristics of the adult fish.

Fig. 216 is intended to show the ordinary appearance and main characteristics of the pelagic larvae of teleostean fishes.

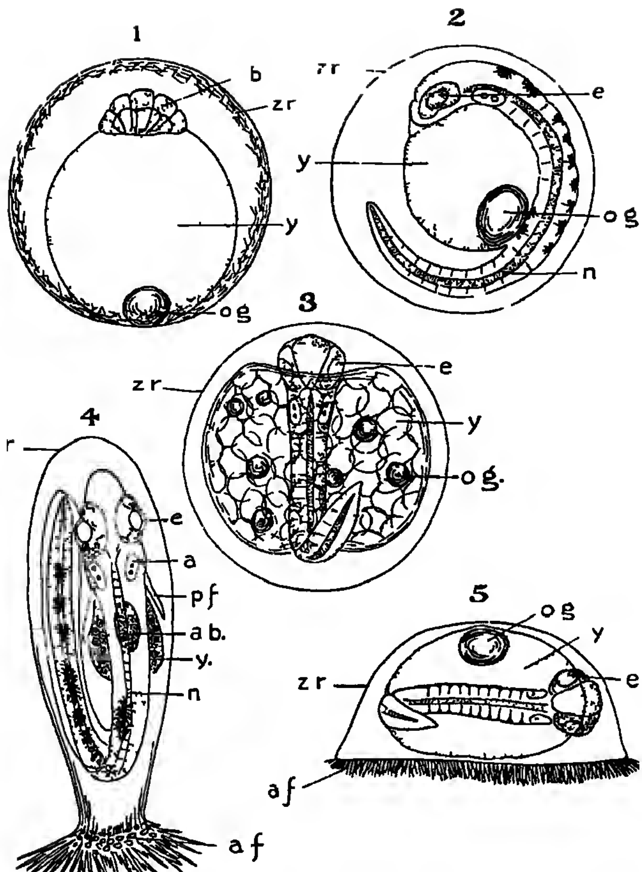


FIG 215 1, 2, 3, Pelagic Eggs (Diagrammatic) × 40 *ca*, 4, Demersal Egg of Goby, 5, Demersal Egg of Spotted Sucker × 30 *ca*

a	Auditory capsule	*n*	Notochord
a b	Air bladder	*o g*	Oil globule
a f	Attachment filaments	*p f*	Pectoral fin
b	Blastoderm	*y*	Yolk
e	Eye	*z r*	Zona radiata

Young

The young of fishes are often very different from the adult in form and colour, apparently especially so in the case of pelagic fishes. Series of the young of almost any species of fish are useful, both as a method of ascertaining the probable rate of growth (where the dates of capture are known) and as throwing light upon the life-histories of allied but less known species.

Often the young of a fish are found in localities widely different from those ordinarily inhabited by the adult, and, especially in the case of fishes of commercial importance, records of the places in which the young are found at various sizes, their comparative abundance, and their seasonal movements, may have a very great practical value.

Certain differences in form and proportions between the young and adults of fishes are so constant and well known as to deserve mention. For instance, the eye of a young fish is, as a rule (and with the known exception of a few oceanic fishes), proportionately larger than that of the adult, and consequently bears a larger ratio to the length of the head and snout and to the interorbital width. The form of the young is not infrequently slighter, and the serrations of the operculum and preoperculum (if present) may be more strongly marked.

Such characters as an elongated beak, prolonged fin rays, or a characteristic colour pattern, cannot be safely looked for in the young, nor can the elongated fin rays of some larvae be expected to persist. On the other hand, the number of fin rays and scales is normally very constant throughout life, and, once the larval phase is passed, the positions of the insertions of the paired fins seem to change but little, however subject to modification their shape and the relative lengths of their rays may be.

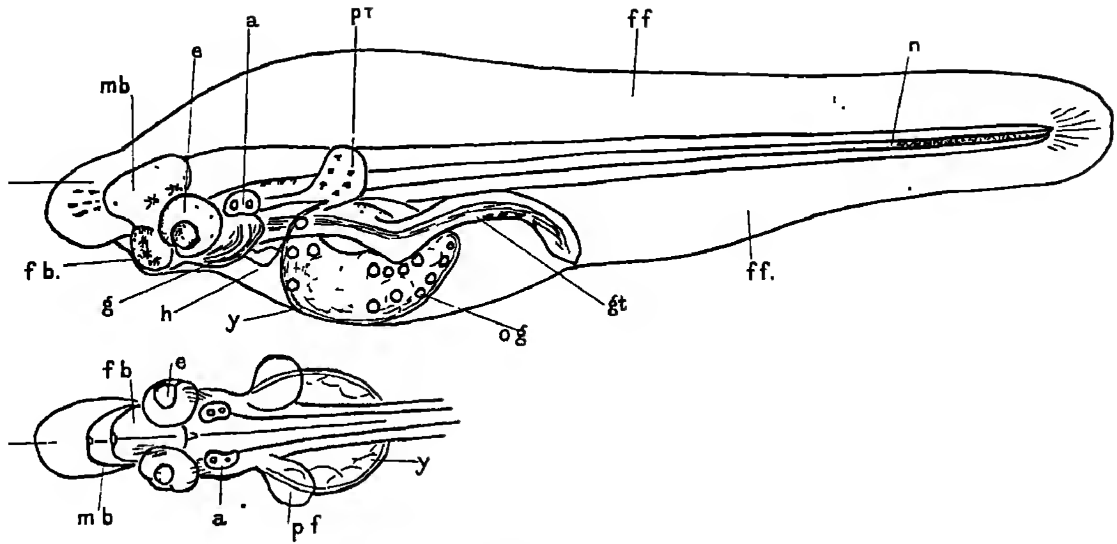


FIG. 216. Pelagic Larva of a Sole (× 30 *ca*)

a. Auditory capsule
e. Eye
fb. Fore-brain
f.f. Fin fold
fl. Float
g. Gills
gt. Gut
h. Heart
m b. Mid-brain
n. Notochord
o.g. Oil globule
p.f. Pectoral fin
y. Yolk

Oceanic Fishes

We advisedly combine under the above heading all the fishes of the open ocean, whether inhabitants of the bottom, the surface, or the intervening waters, because it is often difficult to say into which category any particular fish properly falls, and we believe that many fishes have been described as 'inhabitants of the greatest depths' upon very insufficient evidence.

It is obvious that a trawl or dredge fished on the bottom at a depth of, say, 2,000 fathoms, and drawn open to the surface may, and probably often does, capture fishes in the course of its ascent. It must therefore be remembered that the presence of a fish in any net hauled open to the surface proves no more than that such fish was not captured at a greater depth than the lowest point touched by the net.

There are, of course, many cases in which sufficient evidence is forthcoming of the nature of the habitat of a particular species, especially in the case of those whose normal habitat is in water of not more than 500 or 600 fathoms depth. Such evidence may be based upon a shape unsuited for pelagic life (as in a flat-fish), or for life at the bottom (as in Argyropelecus), as the case may be; or, again, by constant captures in surface nets or by some instrument such as a long line, which is not well adapted to taking fishes in the course of its descent or ascent. The constant presence in considerable numbers of any fish in trawls fished at about the same depth raises a strong presumption that such fish has been captured in the ordinary course of fishing on the bottom; and the presence in a fish's belly of bottom-living organisms points also to a normal habitat on the bottom. Thus we may fairly presume that most deep sea Gadoids, Macrurids, and Scor-

paenoids are bottom fishes, and that the majority of known Stomiatids and Scopelids do not normally live on the bottom.

Evidence that a fish does not live on the bottom is, however, no evidence whatever of the precise depth at which it does live, and it is only within the last few years that the use of suitably constructed mid-water nets has given us any certain knowledge of the nature and distribution of the denizens of any but the surface and bottom layers of the deep sea.

The results already attained certainly indicate that interesting results are likely to attend the extended use of mid-water nets capable of capturing any but the youngest and smallest fishes, and of being opened and closed at ascertainable depths, preferably at least 200 fathoms below the surface, as the lower limit of the surface forms appears to be between 200 and 300 fathoms. In the absence of closing nets series of hauls taken at the same spot with similar nets fished open from different depths, may afford some evidence of the horizon at which a species is most abundant.

In dealing with oceanic fishes it is unsafe to assume that adults are to be found at the same horizon as the larval and young forms of the species to which they belong, and observations showing the different horizons inhabited by the adults and young of any given species would be useful.

We believe that for the capture of such larval and young fishes as live in the upper waters of the ocean, a tow-net should be allowed to sink to about 100 fathoms, since existing records rather point to the region lying between 100 and 25 fathoms as the normal habitat of such forms, which are comparatively scarce at the actual surface. There is some evidence of a nocturnal rise towards the surface and a diurnal fall into deeper water, at any rate

among the smaller fishes found in the superficial hundred fathoms of the open sea, and observations of the extent and character of this rise and fall might well be of interest.

Wherever possible, a temperature record, taken at the depth at which the gear was supposed to be working, should accompany observations made in the open ocean.

Preservation of Specimens

Two preservatives are ordinarily employed in the case of fishes: (1) alcohol, in some form or other; and (2) formalin.

Alcohol has the disadvantage of having to be carried about, of a strength nearly that at which it is used; it therefore occupies a great deal more space than formalin, of which a 5 per cent. solution of the ordinary commercial 40 per cent. solution (i. e. a 2 per cent. solution of pure formaldehyde) is sufficiently strong for all ordinary purposes.

Formalin is unsuitable for specimens which are required for osteological work, as, after a time, it softens the bony tissues. (But see p. 390 for neutral formalin.)

Both preservatives rather rapidly extract the blue and bluish-green colours of many fishes; neither has any great effect on dark pigments, and alcohol dissolves red and yellow pigments more rapidly than formalin. In any case, the colours of fishes—and especially the paler colours—can only be studied after preservation if the specimens are kept in light-proof vessels or, at any rate, wrapped in muslin.

Probably the most satisfactory course is to preserve fishes in formalin, and subsequently to transfer to alcohol those which it is desired to retain permanently as museum specimens; in effecting such a transfer, the usual precaution of dehydrating the specimens gradually and suc-

cessively in 30, 50, and 75 per cent. alcohol should be observed. In practice, many of the fishes which we handle have been transferred after a few weeks preservation in formalin to a mixture of equal parts of 95 per cent. alcohol and the 2 per cent. solution of pure formaldehyde above mentioned; this seems to make an admirable preservative, but, as it has not yet stood the test of time, we can say nothing as to its permanent value.

For preserving larvae the methods above suggested will be found quite satisfactory; preserving solutions containing osmic acid or corrosive sublimate should on no account be used.

XI

PRESERVATION OF MARINE ORGANISMS

BY E. J. ALLEN AND EDWARD T. BROWNE

Introduction

It is impossible within the space allotted to this section to describe in any detail all the numerous methods for the preservation of marine organisms. We have selected the simplest methods, which, if carefully carried out, should yield good results. Those who require their specimens preserved by refined methods for minute microscopical investigations are strongly advised to consult that indispensable book, 'The Microtomist's Vade-Mecum', by Dr. A. Bolles Lee. This book should be in the hands of every marine naturalist, and we have frequently consulted its pages for this chapter. We are also indebted for methods to Sir Sidney Harmer, Mr. R. L. Leiper, and Prof. Graham Cannon, and especially to Mr. A. J. Smith, who has charge of the Preservation Department in the Marine Laboratory at Plymouth.

The subject-matter of this chapter is really in two parts. General information and simple methods such as are within every traveller's power are printed in large type; but the more technical and delicate methods of preservation, for detailed microscopic study rather than faunistic collection, are printed in a smaller type; such methods are suitable only for those who have at their disposal a regular laboratory, on shore or on board a yacht; it is even to be hoped that these latter instructions may prove of value to the smaller fixed marine laboratories in far-away seas.

The successful preservation of marine organisms depends not only upon selecting the right method, but frequently upon a certain amount of practice. A naturalist

going on a foreign cruise, who is not experienced in preservation, is advised to take a course of instruction at a marine laboratory, where he would soon learn the right way of setting to work.

It is quite easy to kill animals by simply placing them in formalin or alcohol, but the results are not always satisfactory. Some may have a lifelike appearance, whilst others may contract into a lump, or even break up into pieces; hence it may be necessary to anaesthetize the contractile animals with cocaine or one of its substitutes, menthol, or some other narcotic before killing them. There are two methods of killing animals, the results of which are quite different. The one is simply to destroy the life of the animal by anaesthetics, without at the same time destroying the life of the tissues, which may survive for some time after the death of the animal. This method is quite suitable for specimens intended for museums and for identification. The other method is to kill the tissues first by certain chemicals, and the death of the tissues causes the death of the animal. When animals are wanted for minute microscopical investigations this latter method is always used, and its success depends upon killing the cells of the tissues before they have time to undergo any change, by chemicals which do not produce a visible change within the cell. The process of 'fixing' the contents of the cell and the shape of the cell is called 'fixation'. An important factor in the success of fixation is the quick penetration of the chemicals through the tissues. Slow penetration gives time for the innermost cells or tissues to undergo post-mortem changes before they are properly fixed.

The preservation of an animal after death, or of its tissues after fixation, is the final stage in the prevention of decay. The preserving fluids commonly used are either

formalin or alcohol, and their preserving action should be understood. We take as an example a big jelly-fish, the jelly of which is more than 90 per cent. water. When alcohol is used as a preserving fluid, all the water in the jelly has to be turned out, and alcohol of a different strength substituted. The first bath of alcohol is considerably reduced in strength by the water from the jelly. Fresh alcohol is then substituted, and this second bath becomes less diluted. The changing of the alcohol must go on until one is sure that the specimen is thoroughly saturated with alcohol of at least 70 per cent. strength. Weak solutions of alcohol have no preserving qualities, and are not proof against bacteria.

Formalin, on the contrary, is a watery fluid, and it has simply to mix with the watery fluids inside the jelly. During the process of mixing its original strength is lessened by dilution, as in the case of alcohol, and a certain quantity is used up in chemical action on the tissues. But so long as there is a small percentage of formalin present the jelly is safe against decay, owing to the powerful antiseptic properties of formalin.

I. *Chemicals used in Preservation*

A. PRESERVING FLUIDS: Formalin, alcohol, formol-alcohol.

B. FIXING FLUIDS: corrosive sublimate, picric acid, picro-formol, acetic acid, chromic acid, Flemming's solution, Hermann's solution, osmic acid.

C. ANAESTHETICS: Cocaine, stovaine, menthol, alcohol.

A. PRESERVING FLUIDS

Neutral Formalin (Formaldehyde, Formol). Formalin and formol are commercial names given to a solution of

formaldehyde, which is a gaseous compound, HCOH, in water. This solution, when first placed on the market, contained 40 per cent. of formaldehyde, but it was found that at this strength the solution was liable to undergo chemical changes and to throw down a precipitate, whereas a weaker solution remained unchanged. The solutions of formaldehyde now vary from 30 per cent. to about 40 per cent. Formalin is a powerful antiseptic, and is manufactured on a large scale for disinfecting purposes; even a very weak solution has a deadly effect upon bacteria. It can be obtained from retail chemists and photographic dealers, but when large quantities are required it is advisable to purchase it directly from a manufacturing chemist, and at the same time to ascertain the strength of the solution. Formalin requires careful handling; its vapour has an irritating effect upon the nose and eyes, but, fortunately, the irritation soon passes away without doing any harm. The action of the solution upon the hands is to harden the skin and to make it slightly rough. Weak solutions, as a rule, are not injurious, but it is advisable to wash one's hands directly after an immersion in formalin, and never to allow the 30 per cent. solution to dry into the skin. There are, however, people whose skin is seriously affected; the skin breaks, after the manner of chilblains, with deep, open cracks, which are painful, and take some time to heal; and the fingers feel numb. None of these effects, however, are permanent, or in the slightest degree dangerous.

The hardening and preserving properties of formalin for animal tissues were discovered independently by Blum and Hermann in 1893, and probably no one has been more benefited by this important discovery than the marine naturalist. Previous to 1893 alcohol was practically the only fluid used for the preservation of marine

animals. It must not be supposed that formalin has completely supplanted alcohol, though the qualities of the former have been loudly praised and the existence of alcohol almost forgotten by some naturalists.

Formalin has two great advantages over alcohol: (1) It does not usually produce a shrinkage of the tissues; therefore it is a splendid fluid for the preservation of delicate soft-bodied animals, such as jelly-fishes. (2) It is a great time-saving fluid, as specimens can be placed straight into formalin without requiring any further attention; whereas with alcohol it is usually necessary to pass specimens through a series of different grades of strength, each grade requiring a certain length of time, or to change a strong grade several times so as to get rid of the watery fluids within the specimens.

To marine naturalists formalin has two special advantages: (1) It can be diluted with sea-water, as well as with fresh water. When alcohol is mixed with sea-water, certain salts in the latter are precipitated, and the solution becomes turbid. (2) It is sold as a concentrated solution, and for our purposes it has to be considerably diluted with water; it is therefore a convenient fluid to take on board a ship, where storage space is frequently limited, and on expeditions, when weights have to be carefully considered.

As a rule most marine animals can be satisfactorily preserved in formalin, but there are exceptions, where formalin is inferior to alcohol, or even quite useless. It destroys completely certain kinds of calcareous structures, such as the spicules in calcareous sponges and the calcareous skeleton of some larvae. The dissolving away of calcareous substances is due to formic acid, which is nearly always present in formalin. This can be prevented by the use of **neutral formalin**, which is easily made by adding borax to the solution. From 5 to 10 gm. of borax should

be added to 1 litre of the formalin solution, until on testing with phenolphthalein a good red colour is produced. An excess of borax will do no harm. We recommend that such neutral formalin be used for all purposes. The action of formalin upon animal tissues is variable, depending upon the chemical composition of the tissue; it may harden, soften, or destroy.

There is one group of animals for which formalin is not suitable—namely, the Ctenophora. Its effect upon the Ctenophores is interesting and worth mentioning here. Pleurobrachia looks splendid after it has been killed in formalin 5 per cent. in sea-water, and remains all right for a few months. Later on its jelly shows visible signs of shrinkage. The shrinkage continues until the specimen becomes quite shrivelled up, and eventually disintegrates. Beroe frequently shrivels up in the course of a few days, or the process of shrinkage may be extended over a few months. Bolina, one of the most delicate Ctenophores, dissolves at once in formalin.

Strength of Solution. Before dealing with the strengths of the solutions suitable for the preservation of marine animals, it is necessary to make quite clear the difference between formaldehyde 10 per cent. and formalin 10 per cent. Formalin, as purchased, contains a definite quantity of the gaseous formaldehyde dissolved in water, and the percentage of formaldehyde present should be stated on the manufacturer's label thus: 'Formaldehyde 40 per cent.' To make up a solution so as to contain 10 per cent. formaldehyde we must add three parts of water to the quantity taken out of the 40 per cent. stock bottle (100 c.c. of formaldehyde 40 per cent. + 300 c.c. of water). But if we make up a solution to contain 10 per cent. of formalin, then to the quantity taken out of the bottle labelled 'Formaldehyde 40 per cent.' we add nine parts of water

(100 c.c. of formaldehyde 40 per cent. + 900 c.c. of water). This 10 per cent. solution of formalin is equivalent to formaldehyde 4 per cent., and formaldehyde 10 per cent. is two and a half times stronger than formalin 10 per cent.

Both methods of making up working solutions are in use; and as authors frequently use the terms 'formaldehyde' and 'formalin' indiscriminately, without giving a clue as to whether the percentages refer to formaldehyde or formalin, there is consequently much confusion.

There can be no doubt that the scientific method is to reckon the percentage in the quantity of formaldehyde present, especially as the commercial solutions of formaldehyde now vary from 30 to 40 per cent.

Formaldehyde 10 per cent. is a constant strength, whereas formalin 10 per cent. is liable to vary in the amount of formaldehyde present, according to the strength of stock solution.

The unscientific method of making solutions prevails, partly because all commercial solutions were sold for many years as 40 per cent. strength, and partly because it is very easy to read percentages in a centimetre measure.

Successful preservation with formalin depends upon using sufficient formaldehyde to fix every cell in the specimen, and a surplus sufficient to prevent subsequent maceration. A specimen which is properly fixed and preserved in 50 c.c. of formaldehyde 4 per cent. can also be fixed and preserved in 50 c.c. of formaldehyde 2 per cent., providing that the latter solution be changed once. It is much the safest plan to allow the specimen to soak for two or three days in formaldehyde 2 per cent., and then to change it into formaldehyde 4 per cent. It is a great mistake to be stingy over the formalin; use it freely, and change the solution at least once, or, if this

cannot be done, make up the strength by adding a very small quantity of the strongest formalin.

There can be no doubt that collectors, as a rule, do not use sufficient formalin, and forget that their specimens are very liable to remain untouched for two or three years. Specimens which are worth a place in a permanent collection are worth a little extra trouble and a little extra formalin.

Concerning the strength of the solutions of formalin for preservation there is a difference of opinion. Some workers use weak and others fairly strong solutions. A good, useful solution for general work is formaldehyde 4 per cent., which is made up thus: Formaldehyde 40 per cent. (or about 40 per cent.), 1 part; water, 9 parts. The bottle may be labelled either 'Formalin 10 per cent.', or 'Formaldehyde 4 per cent.'

If the commercial solution is purchased at 30 per cent. strength, then the following proportions should be taken: Formaldehyde 30 per cent., 1 part; water, 6½ parts. This solution contains formalin 13·3 per cent., and is equivalent to formaldehyde 4 per cent.

Some animals can be killed at once by dropping them into formalin 10 per cent., or by pouring the solution into the sea-water containing the animals; but others are not killed quickly enough, and have sufficient time to contract or to cast off appendages. For the latter class of animals either an anaesthetic, like cocaine or stovaine, may be used before adding the formalin, or another chemical, like picric acid, added to the formalin, to quicken the killing action.

The value of formalin in fixation is to prevent shrinkage, and for this purpose it has been added with success to several well-known fixative formulae.

Alcohol. The alcohol used for preserving purposes is pure methylated spirit, known as Industrial methylated

spirit, upon which excise duty must be paid within the limits of the British Excise, or an exemption permit obtained from the Custom House, London. The ordinary methylated spirit obtained from a dealer is quite useless for preserving marine animals, as it contains certain chemicals, put in to prevent people from drinking it. Directly water is added to this liquid it takes on the appearance of milk, and a very fine precipitate is thrown down. All attempts to get rid of this precipitate are only waste of labour, as an additional drop of water starts a fresh precipitate in a filtered solution.

Pure methylated spirit when purchased is commonly called '90 per cent. alcohol', though its strength may be slightly greater than 90 per cent. This may be diluted with water so as to make up solutions containing 30 per cent., 50 per cent., and 70 per cent. of alcohol. These solutions can either be made up by the use of an alcoholometer, or by adding definite volumes of water, according to the table given below.

TABLE FOR DILUTING ALCOHOL
(From Bolles Lee)

Grade Required Per cent.	Original Grade				
	90 per cent.	80 per cent.	75 per cent.	70 per cent.	50 per cent.
80	13·8	—	—	—	—
75	21·9	7·2	—	—	—
70	31·0	15·3	7·6	—	—
60	53·6	35·4	26·4	17·5	—
50	84·7	63·0	52·4	41·7	—
40	130 8	104·0	90·7	77·5	25·5
30	206·2	171·0	153·6	136 0	67·4

To use this table find in the upper horizontal row of figures the percentage of the alcohol that it is desired to dilute, and in the vertical row to the left the percentage of the alcohol it is desired to arrive at. Then follow out

the vertical and horizontal rows headed respectively by these figures, and the figure printed at the point of intersection of the two rows will show how many volumes of water must be taken in order to reduce 100 volumes of the original alcohol to the required grade. Thus, if it be required to manufacture some 70 per cent. alcohol, starting with 90 per cent., we find the figure 70 in the vertical column, and at the point of intersection we read 31, showing that 31 volumes of water must be added to 100 volumes of 90 per cent. alcohol.

A rougher method of diluting 90 per cent. alcohol is as follows: Take a number of volumes of 90 per cent. equal to the percentage desired, and add a number of volumes of water equal to the difference between the percentage desired and 90. Thus, to make 70 per cent., take 70 volumes of 90 per cent., and add 20 of water; to make 50 per cent., take 50 volumes of 90 per cent., and add 40 of water; and so on.

All solutions of alcohol should be made with pure fresh water (ordinary ship's water should be filtered first, even if distilled). Water loaded with mineral salts gives a precipitate when mixed with alcohol, and unless the precipitate is removed by filtration or decantation the specimens generally become coated with a very fine dirty sediment.

Alcohol by itself is not good for fixing purposes, but is generally used in combination with other chemicals, as it increases their penetrating power. It is a good hardening agent, but unfortunately it produces a considerable amount of shrinkage in the tissues. As a preservative it is excellent, and the safest of all preservatives for specimens intended for permanent collections.

The strength of the alcohol commonly used for the preservation of animals lies between 70 and 80 per cent. The minimum strength should be rigidly fixed at 70 per

cent. A slight increase over 70 per cent.—say 75 per cent.—is an advantage, because it provides a margin against evaporation.

Delicate, soft-bodied animals should not be placed straight into 70 per cent., but first into 30 per cent. alcohol for a few hours, and then in 50 per cent. for several hours, and each solution should be changed at least once. Transfer from 50 per cent. to 70 per cent. The passage through these different grades of alcohol reduces the amount of shrinkage, and gradually removes the watery fluids from the body of the animal. It is very important for all the tissues of the body to be thoroughly permeated with 70 per cent. alcohol, hence the necessity of changing at least once the 70 per cent. solutions. As weak solutions of alcohol quickly produce maceration of the tissues, it is advisable not to leave specimens too long in the weak grades.

Alcohol which has become weakened by water from the animals soaked in it (so long as it does not contain chemicals) should be kept, and coarse animals—Crustacea, fish, starfish, &c.—can have their first brief soaking in this before being transferred to stronger alcohol. An alcoholometer is useful here. This spirit should be thrown away when of a less strength than 30 per cent. But if it is not necessary to economize alcohol, then animals with hard coats, such as crabs, or with firm bodies, such as fishes, can be placed after death at once in 70 per cent.; after a preliminary soaking the alcohol must be changed. The number of changes required depends upon the size of the animal and the quantity of alcohol used for each bath. The most important thing is to keep up the strength of the final solution, and not to store away the specimens until they have become thoroughly permeated with at least 70 per cent. alcohol.

It is well to remember that the weakest grade of alcohol is the heaviest, and remains at the bottom of the vessel. When passing specimens through different strengths of alcohol, an occasional stir up should be given, just to help on the process of mixing, and to bring the stronger alcohol into contact with the specimens.

Formol-Alcohol (Formalin Spirit). This is made by adding 5 per cent. of commercial formol (40 per cent. formaldehyde) to alcohol of 70 per cent. and should be neutralized by the addition of borax (see p. 390), thus: Alcohol 70 per cent., 95 c.c.; formaldehyde 40 per cent., 5 c.c.

Formol-alcohol is one of the best preserving fluids for general collections which are not required for histological work. The specimens are put directly into the fluid, which should be changed after about twenty-four hours. In the case of animals which contract readily, they should be anaesthetized with cocaine or one of its substitutes such as stovaine, menthol, magnesium sulphate, or weak spirit, before being put into the formol-spirit neutralized with borax.

B. FIXING FLUIDS

Corrosive sublimate (bichloride of mercury, $HgCl_2$) is probably the most generally useful fixing fluid, when specimens are required for minute study of their cell-structure.

It is used either as a simple saturated solution in water, or can be mixed with glacial acetic acid if it is not desired to preserve calcareous structures. For marine animals the following proportions are recommended: Bichloride of mercury, saturated solution in distilled water,[1] 95 c.c.;

[1] One hundred cubic centimetres of distilled water will dissolve 6 or 7 gm. of bichloride of mercury at ordinary temperatures. It is best to add an excess of

glacial acetic acid, 5 c.c. The acetic acid should be added to the corrosive sublimate just before use. Both the simple saturated solution of sublimate and the sublimate-acetic mixture kill and penetrate more rapidly if used hot, at a temperature of 70° or 80° C. Many forms can be killed and fixed in an extended condition by plunging them rapidly from a dish of sea-water in which they are well expanded into a vessel containing hot corrosive sublimate solution.

The time during which objects must remain in corrosive sublimate solutions varies very much, especially with their size. Small delicate organisms will be sufficiently fixed in ten to fifteen minutes. Larger organisms and pieces of compact tissue may remain from one to twenty-four hours with advantage.

After removal from the sublimate solution or sublimate-acetic mixture, the objects are transferred direct to 70 per cent. alcohol, to which a few drops of tincture of iodine[1] are added. A considerable volume of the alcohol should be used, and enough iodine to make it of 'a good port wine colour'. The colour is gradually destroyed by the corrosive sublimate. When the alcohol has lost all the colour it should be changed, and fresh tincture of iodine added. This process should be repeated until the iodine colour remains for twelve or twenty-four hours, when the object is removed to fresh 70 per cent. alcohol, without the addition of iodine, and given several changes. Thorough washing with the pure alcohol is necessary if the deposition of red crystals in the object is to be avoided.

the bichloride and dissolve in hot water. On board ship it is easiest to have a big bottle, with an inch or two of powdered corrosive sublimate at the bottom, and fill it up with water every night; it will be saturated by morning if shaken occasionally.

[1] Tincture of iodine is made by dissolving iodine in strong alcohol.

Corrosive sublimate is more soluble in alcohol than in water, and a saturated solution in 70 per cent. alcohol is sometimes used for fixing with good results. It is also more soluble in sea-water (or common salt solution) than in distilled water, and the sea-water solution is sometimes recommended. In both these cases the subsequent treatment of the specimens is similar to that described above, excepting that after using the sea-water solution the material should be washed in one or two changes of fresh water or distilled water.

This is a most deadly poison if taken internally, and a saturated solution looks exactly like plain water.

Picro-formol-acetic. (**Bouin's Fluid.**) This solution is a splendid fixative, with a great power of penetration and kills very quickly. In many cases it is much better than the corrosive sublimate mixtures. Bouin's formula is: Picric acid, saturated aqueous solution, 75 parts; formalin 30 or 40 per cent., 25 parts; acetic acid, 5 parts.

When fixation is complete wash out the yellow colour with alcohol 70 per cent. and store in the same.

This fluid, diluted with an equal volume of water, may be used for preserving large animals for dissection.

Picric acid is a bright yellowish flaky powder, which is scheduled under the Explosives Act. In a glass bottle by itself there is good evidence that it is a harmless substance, especially when kept under water, but on the discharge near it of a detonator it becomes a violent explosive. It is used in the manufacture of bombs and shells, under the names of melinite, lyddite, &c. The Board of Trade Regulations forbid its conveyance on board a ship.

Picric acid is often used for rapidly killing marine animals, and is a good fixative, with a great penetrating power. It may be either used alone or in combination with other chemicals. As a saturated solution in water is always

used, there is no trouble about making up the stock solution. Simply place some picric acid in a bottle and fill up with water. If clean fresh water should not be available, then sea-water may be used instead. A little picric goes a long way, for one part of picric dissolves in about eighty-six parts of water; but it is more soluble in hot water.

There is one disadvantage with picric acid—namely, the trouble of removing the yellow stain. After the specimen has been properly fixed in picric, transfer it to alcohol, and change the alcohol several times, until the fluid is no longer yellow. It does not matter very much about the specimen remaining yellow. To remove all traces of the stain from the specimen generally takes several days and many changes of alcohol. Specimens, after they have been fixed with picric, should not be soaked in water; but if they are not wanted for histological work, then formalin may be used instead of alcohol.

Chromic Acid. Weak solutions of chromic acid in water are often useful; 2 per cent., 1 per cent., and 0·5 per cent. solutions are generally employed, the specimens remaining in the solution for some hours. After chromic acid the specimens should be very thoroughly washed in fresh water, being allowed to remain in running water for even twenty-four hours. After washing they are transferred to 30 per cent. alcohol, then to 50 per cent. alcohol, and finally to 70 per cent. alcohol, in which they may be kept. Chromic acid specimens are best kept in the dark.

The disadvantage of chromic acid is that objects preserved in it are often difficult to stain.

Chromo-acetic Acid. Chromic acid, 0·2 to 0·25 per cent.; acetic acid, 0·1 per cent., in water. Proceed as in the case of chromic acid.

Flemming's Fluid (Strong). One per cent. chromic acid, 15 parts; 2 per cent. osmic acid, 4 parts; glacial acetic acid, 1 part.

This is one of the best fixing agents for preserving the minute structure of cells. Only small pieces of tissue should be put into this fluid, as it does not penetrate well. The specimens should

remain in the fluid for several hours, or if they are large for several days. Wash well in running water, as in the case of chromic acid specimens, and bring gradually to 70 per cent. alcohol.

The specimens are generally very much blackened by the osmic acid in the solution, and are often difficult to stain, especially if the washing has not been sufficiently thorough.

Flemming's Fluid without acetic acid should be used if it is wished to preserve mitochondria and such-like bodies in the cells.

Hermann's Solution. This is similar to Flemming's solution, excepting that 1 per cent. platinum chloride is used instead of 1 per cent. chromic acid. The solution is used in the same way as Flemming's solution. It is said to preserve the protoplasmic structures better than Flemming's fluid.

Osmic Acid. A very powerful killing agent for small organisms, such as Protozoa or small Crustacea. It is generally used in $\frac{1}{2}$ per cent. solution. The vapour of the acid is also used, a drop of water containing minute organisms being put in a closed dish in which a few drops of osmic acid solution have been placed. A great disadvantage of osmic acid is that it blackens the specimen very much, especially if the tissue is of a fatty nature; the blackening can be removed with a weak solution of chlorine, which does not improve the tissues for microscopic work.

Preserving Minute Organisms. The preservation and storing of minute organisms, singly or in quantity, is made certain and easy by the following arrangement. Pieces of glass tubing of about $\frac{1}{4}$ in. internal bore are cut in inch lengths, and one of the open ends is rounded in the flame. The slightly throttled end is closed with a loose plug of pyroxylin. This plug should not be too tight but should be compressed enough to prevent any of the small organisms passing through. A convenient method is to hold the throttled end of the tube against the left thumb and press down the pyroxylin plug with a glass rod cut off square at one end. This compresses the plug and at the same time ensures that its upper surface is flat and does not extend in a layer up the sides of the tube, an important point, because, if the upper layers of the pyroxylin are diffuse, they obscure any small organisms in the tube.

The fluid containing the small organisms can now be filtered through the tube. The specimens remain in the tube when the fluid is drained by holding the tube with forceps on a piece of

blotting-paper. They can now be fixed in the tube by squirting fixative into the open end of the tube. This is best done with a fine pipette by allowing the fixative to run *slowly* down against the inside of the tube. If it is allowed to run in too quickly air bubbles always lodge above the organisms. If the organisms are extremely small it is best to fix them in a watch-glass and then filter them off through the tube.

A specimen tube of appropriate size is then filled with the washing fluid, e.g. 70 per cent. alcohol after Bouin or formalin fixation—to a height about two-thirds of the open tube. The fixative is then drained from the organisms and the open tube immersed in the washing fluid. The latter rises through the pyroxylin plug and reaches the specimens. It is obvious that this process can be repeated with as many washing fluids as necessary until the storing fluid is reached.

If the pyroxylin plug is too loose it slips up the open tube during these washing processes. If this happens, rather than run the risk of distorting the specimens by removing them to a new tube, it is better to fill the open tube through the open end with the washing fluid before immersing them in the specimen tube. In practice it is perhaps better always to do this rather than stand the chance of dislodging the pyroxylin plug.

When the specimens have been brought by this process up to the storing fluid a small index label is inserted in the tube. It is now completely immersed in the fluid, care being taken to see that the specimen does not float out of the open end. While still immersed the open end is loosely plugged with pyroxylin and the tubes can then be stored away in large numbers in ordinary storage jars.

Pyroxylin is used instead of ordinary cotton-wool because it is soluble in clove oil or in a mixture of alcohol and ether. Thus a single minute organism can be fixed and stored in this way—and incidentally stained while still in the tube—and then if the tube is brought up to absolute alcohol, clove oil added and placed on a warm bath, the alcohol evaporates and the pyroxylin dissolves into a kind of celloidin syrup. The specimen is left in the syrup and can be directly mounted or the syrup can be hardened for embedding in paraffin wax.

C. ANAESTHETICS

If put immediately into a fixing fluid many marine animals contract and shrink up. It is therefore necessary, in order to get well-expanded specimens, to anaesthetize before killing. The substances generally used for this purpose are cocaine or stovaine, menthol, and very weak alcohol. Chloral hydrate is also sometimes used, as well as other anaesthetics. It is to be noted, however, that the methods of anaesthetization are not to be recommended for use in the tropics; the animals die and rot too quickly in small bodies of water.

Cocaine (hydrochloride of cocaine) is a useful and powerful anaesthetic, but it is now difficult to obtain. Stovaine may be used as a substitute, but it is not as good. A 1 per cent. solution in distilled water should be made up and a few drops added to the sea-water containing the living specimen in a fully expanded condition. It is best to increase the dose at intervals, and not to add the full quantity at once or suddenly. A sudden overdose frequently makes the animal contract; if it does not show signs of expanding within about three minutes, then remove it into a vessel of clean sea-water and let it revive. Try next time with less cocaine.

Solutions of cocaine do not keep very long, and are usually spoilt by fungoid growths. It is advisable not to make up more than 100 c.c.

Directly the animal becomes anaesthetized pour in the killing or fixing solution. After adding corrosive sublimate or picric acid a precipitate is frequently produced. The precipitate consists of cocaine, and is soluble in alcohol or in an excess of picric acid. The safest plan to insure good fixation and at the same time to get rid of the precipitate is to remove the specimen to another vessel and add more fixative.

Menthol. This substance is now much used, and with great success, for anaesthetizing the larger marine animals.

The animals are put into a clean vessel, with sufficient sea-water to cover them well, and the surface of the water is strewn with crystals of menthol. As the menthol dissolves the animals expand, and eventually become quite anaesthetized. In from twelve to twenty-four hours they may be transferred to a suitable fixing fluid in which they will be preserved with little, if any, contraction.

Anemones, Holothurians, Ascidians, and many Molluscs have been successfully treated in this way.

Alcohol. Seventy per cent. alcohol, added drop by drop to sea-water in which marine animals are living, will often cause them to die in an expanded condition. The rate at which the drops are added varies in different cases, and no definite rules can be given.

Chloretone is recommended by Bigelow as a most satisfactory anaesthetic for medusae and siphonophores. A 1 per cent. solution is used, and a small quantity is added to the sea-water containing the specimens.

Magnesium Sulphate, either in saturated solution into which the animals are plunged, or by adding crystals to the water in which the animals are living, often gives good results.

II. *Notes on Storing Specimens*

Bottles with Cork Stoppers. Bottles and tubes are generally sold with inferior corks, which are often perforated with small holes. It is advisable to order corks of a good quality, such as are used in chemical laboratories; bungs and shives should be avoided. A good cork makes an excellent stopper, provided that it fits nicely and is well driven in. For a cork to grip firmly, a bottle with a slightly tapering neck is required, a little wider at the bottom than at the top, so that when the cork swells it cannot slip out. The ordinary straight glass tube requires a cork with straight sides, and the cork should be well squeezed before being put in. Even then it is liable to slip up, especially if the tube contains alcohol. There is always an uncertainty with corked bottles. They are safe for short periods up to about twelve months, and after that they should be examined at least once a year. The risk of leakage and evaporation can be considerably reduced by coating the cork with paraffin wax, and this should always be done before finally storing away the bottles. The method is quick and simple, and the gain in security is well worth the trouble. It is as follows:

After corking, wipe the top of the cork and the rim of the bottle, and then place the bottle aside for a day, or longer, to dry. It is very important that the cork should be perfectly dry, and no fluid in the crevice between the rim and the cork. When the bottles are ready for coating, melt some hard paraffin wax (paraffin wax candles or any kind of hard wax may be used) in a small metal pot. A glue-pot is a great comfort for this purpose on board ship; it can be stood on the galley-range. Then dip the cork deep enough to cover about a quarter of an inch of the glass. After the first coat has solidified and cooled, give a second dip, quickly in and out, or else the first coat will have time to melt off. A bottle or tube properly sealed with paraffin wax will stand against evaporation for several years. Some bottles and tubes recently examined after being stored away for eight years were quite sound; but a few showed a slight loss of fluid, though the paraffin coating was externally flawless and perfect. On further examination it was found that the paraffin was no longer adhering to the glass.

Miniature bottles, with a capacity of about ½ oz. (15 c.c.), made of thin glass and fitted with a good cork, are very useful and convenient for small specimens. All bottles should have wide mouths, and the 1 oz. (30 c.c.), 2 oz., 3 oz., and 4 oz. sizes are recommended.

Some wide-mouthed bottles are sold with a cork fastened on to a wooden cap. They look very neat and nice, but have proved to be an utter failure for fluids.

Alcohol dissolves out the brown tannin in cork, and the specimens usually absorb the tannin, and turn to a brownish colour. If the specimens are wanted for histological work, corks should be avoided and glass stoppers used.

Bottles with Glass Stoppers. For the permanent storage

of specimens a glass-stoppered bottle is not to be surpassed. The small sizes—½ oz. (15 c.c.) to 4 oz. (120 c.c.) —are most suitable for general use, and when larger sizes are required it is much cheaper to select a good glass-capped fruit-jar.

Glass-stoppered bottles vary considerably in quality and in price. The cheap ones have rather coarsely ground stoppers, not always fitting accurately in the neck of the bottle. The best quality have very smooth-ground stoppers, each ground to its bottle; they fit accurately, and are usually numbered.

Every one who has had any experience with glass-stoppered bottles sooner or later finds out that even the best quality bottle is not absolutely proof against the evaporation of alcohol. To prevent evaporation the stopper is often coated with vaseline or lard. The disadvantage of vaseline is that it becomes too liquid in warm weather, and it gradually works its way down the stopper and drops into the fluid, forming a harmless oil globule in alcohol, and an oily scum over formalin. Lard, on the contrary, slowly loses its greasy nature and dries up. A mixture of vaseline and beeswax is perhaps the best substance for glass stoppers. It is made by first melting in a pot a few small lumps of beeswax, adding some vaseline, and well stirring up. The consistence of the mixture, when cold, should be like soft butter on a warm day. The beeswax raises the liquefying-point of vaseline. The whole of the ground glass of the stopper should not be coated with the mixture, but only the uppermost part. Just put on a narrow band with the aid of a penknife or a flat stick.

When glass-stoppered bottles containing specimens are sent by post or by train, the stoppers should be tied down with string or held by a rubber band.

Glass Jars with Metal Caps. These jars are commonly sold for the storage of jam, honey, and other substances. Their sizes are denoted by their capacity for weight, and not by fluid capacity. The most useful sizes are the ½ lb. (holding 5 fluid oz., or 150 c.c.) and the 1 lb. (350 c.c.). The metal cap screws on to the rim of the jar, and inside the cap there is a thin sheet of common cork, which is quite satisfactory for jam, &c., but not for fluids. The cap is sometimes made of iron coated with tin or some other white metal, or it may be made of a soft or hard alloy of some kind or other. These jars, as purchased, are very useful just for temporary purposes, but not suitable for a long storage of specimens. As the jars are very cheap and very convenient, several attempts have been made to render them watertight and to keep the fluid away from the metal. Alcohol, and especially formalin, attacks the metal cap, and if left long enough the metal corrodes away and the cap becomes perforated. The most successful method for making these jars serviceable is the one used in the laboratory at Plymouth. The cork disk inside the cap is removed, and a disk of rubber, punched to the exact size of the cap, is fastened in the place of the cork.

Glass Jars with Glass Caps. These jars are used for preserved fruits in syrup, and are the best jars to take on collecting expeditions. The cap is a glass disk with a projecting rim, which rests upon a rubber ring fitted on the neck of the bottle. There are several devices for holding down the glass cap, and it would be difficult to say which is the best. The jars are more costly than those with metal caps, and run in larger sizes, from 1 to 4 lb. (1,800 c.c.). An excellent jar in the series is known as the 'Apricot' jar, which is a squat 2 lb. jar (1,000 c.c. capacity), with an extra large mouth. Messrs. Kilner Bros.

make a special screw-top jar with a capacity of about 2,600 c.c. and an extra wide mouth.

The common 'sweetstuff' jar, with a glass stopper, to which is fitted a cork rim, is not recommended for travelling purposes. These jars are not intended for fluids, and usually leak. The cork strip cracks easily, and the stoppers are difficult to raise.

For large specimens stoneware tobacco-jars, with extra wide mouth, which have a top that can be screwed down on a rubber ring, are very convenient. They can be obtained in several sizes.

For collecting expeditions jars fitted with rubber disks can be recommended, and for storage special wooden boxes should be made, fitted with partitions for the isolation of each bottle, and the bottom and partitions and the inside of the lid lined with thick felt. With these boxes the jars are always ready for use; there is no unpacking or packing up.

Glass Tubes with Cotton-Wool Plugs. This method is often used for the isolation of specimens in small tubes, and it can be thoroughly recommended. The tubes are tightly plugged with absorbent cotton-wool covered with good tissue or fine parchment paper, instead of a cork, and they are at once put into a wide-mouthed glass jar, filled with the same fluid as in the tubes. It is an excellent system for collecting expeditions, as the small tubes are safe inside the large jars, and are quickly packed. It is advisable to place a layer of wool at the bottom of the jar, a little between the tubes, and some on the top. This will prevent the tubes from rattling about inside the jar, and reduce the risk of breakage. The large jar must be filled to the brim with fluid, so that all the tubes are properly immersed.

Damage done by Air Bubbles in Tubes and Bottles.

Although great care is sometimes taken in preserving specimens, yet no care is taken in properly storing them for travelling. There is nothing more disastrous to delicate animals than an air bubble rolling up and down a narrow tube, or a large air-space in a bottle which is subject to the rolling of a ship or the shaking of a railway train. There is not the slightest difficulty in filling a bottle with fluid up to the bottom of the stopper, but narrow glass tubes require special treatment. Fill the tube to the brim with the preserving fluid, and insert a tight-fitting plug of absorbent cotton-wool, which should have been previously soaked in the same fluid. After a little practice it is quite easy to insert the plug without introducing an air bubble. The tubes can either be stored in a large glass jar, filled with the preserving fluid, or corked and sealed with paraffin wax.

Labels. Those who are contemplating an extensive collecting expedition should provide themselves with proper labels, made of good paper, upon which, at least, should be printed: 'Date', 'Number', 'Locality', 'Preservation'. The best and safest place for a label is no doubt inside the bottle, and as the label will be in the fluid, it is necessary to select a tough, unglazed paper (see p. 460). A record which is frequently omitted on labels is the method of preservation. It is by no means an unimportant detail, especially when the specimens are handed over to a specialist for examination.

III. *Preservation*

Plankton. The preservation of the whole catch of a townet just as it comes on board, without any sorting of the specimens, is a simple operation. Animals with hard coats, such as Crustacea, stand the treatment very well, but soft-

bodied animals, such as jelly-fishes, usually contract and become very much distorted.

The best method is to pour the plankton from the can (at the bottom of the tow-net) into a glass jar. Stir the plankton round with a rod, and at the same time pour in a little formalin, 5 per cent. or 10 per cent. Take out the larger animals with lifter and pipette. Keep on stirring for about a minute, so as to mix thoroughly the formalin with the sea-water; then allow the plankton to settle to the bottom. Soon after the plankton has settled, pour off as much of the fluid as possible, and transfer the plankton to a bottle. Allow the plankton to settle, and reduce the quantity of fluid to a minimum. The next step is to fill up the bottle with formalin, 5 per cent. or 10 per cent., and occasionally give the contents of the bottle a stir up. A bottle should not be more than half full of plankton. It is advisable after a few days either to pour off the formalin and add a fresh supply, or to pour in a very small quantity of strong formalin. Opalescence of the fluid is a sign that it needs changing.

Another method is first to kill the plankton by pouring some picric acid solution into the glass jar, and then add a little formalin, 5 per cent. or 10 per cent. Leave the plankton in this very dilute picro-formol solution for an hour or two, occasionally stirring up. Finally transfer the plankton to a bottle, and fill it up with formalin, 5 per cent. or 10 per cent. The fluid will remain yellow, but the small quantity of picric present may be neglected. It is important to use plenty of formalin, for an extra strong dose does no harm, and to remember occasionally to stir up the contents of the bottle.

Corrosive sublimate must never be used instead of picric acid for this wholesale method of quickly preserving plankton. The presence of corrosive sublimate in formalin

leads to the formation of a precipitate, which adheres firmly to all the specimens.

Protozoa may be preserved in weak osmic acid. If they are numerous, the osmic acid may be added to the water containing them (2 or 3 drops of ½ per cent. osmic to 10 c.c. of water); the Protozoa are allowed to settle, or, better, are separated by means of a centrifuge. They should be stained with dilute picro-carmine, and brought gradually into 70 per cent. alcohol.

If one is dealing with a few specimens only in a drop of water on a slide, the drop may either be exposed to osmic acid vapour, or some solution may be run in under a cover-glass.

Radiolaria should be preserved with dilute osmic acid, or with corrosive sublimate. Acanthometra killed with corrosive sublimate (about one minute in saturated solution) keep better than those preserved in osmic acid.

Porifera. One simple and ready method of preserving sponges satisfactorily is to hang them up in strong alcohol (the strongest obtainable, absolute alcohol giving the best result). By hanging them in the fluid the strength of the alcohol surrounding them is kept as high as possible. They should be transferred to fresh alcohol after a few hours, and again in the course of a day or two.

They may also be well preserved by plunging them into osmic acid (1 per cent. solution), in which they should remain for from three to five minutes. Small specimens taken from a rock-pool and put immediately into tubes containing osmic acid give excellent preparations. Larger sponges will need to be cut into small pieces before being placed in the preserving fluid, and the sooner this is done after the sponge is taken from the sea, the better the result will be.

Hydroids may be easily killed and preserved by simply

placing them in formalin 10 per cent., but one must not expect to see the hydranths nicely expanded by this method.

Most gymnoblastic hydranths can be killed in a fairly good state of expansion by quickly plunging the expanded colony into warm corrosive sublimate and moving it slowly up and down for about a minute. Wash afterwards in water to remove the corrosive, and transfer to formalin or alcohol. A safer method for catching the hydranths nicely expanded is to anaesthetize with menthol, which takes many hours, and then to kill with corrosive. Many calyptoblastic forms can be killed in a fair state of expansion by simply plunging the colony into warm corrosive and giving it a gentle shaking. They are more sensitive to the presence of anaesthetics than the gymnoblastic forms, and to kill the hydranths well expanded requires a considerable amount of practice.

Hydromedusae. The successful preservation of medusae, or any other delicate, soft-bodied animals, depends to a great extent upon the healthy condition of the specimens. Directly the tow-net comes on board, the Plankton must be poured into a glass jar, and the jelly-fishes at once picked out by means of a pipette or some other handy instrument, and placed in a glass vessel containing sea-water. This glass vessel must be absolutely clean and free from the slightest trace of chemicals.

The medusae should be given about half an hour to expand and to recover from the shock. If the medusae after the first half-hour look in a sickly condition, the sooner they are preserved the better; but if in a healthy condition there is no need to hurry over their preservation. They may be left in the vessel for several hours, provided that it is kept in a cool place out of the heat of a summer's sun.

The simplest and quickest method for preserving either a few specimens or several dozen is by pouring diluted formalin into the sea-water. The secret of success depends upon keeping the medusae in motion whilst the formalin is being poured in. First stir the medusae very slowly and very gently round and round with a clean glass rod. When all are in motion, begin pouring in the formalin slowly and gently down the side of the vessel. About 10 c.c. of formalin 10 per cent. may be taken as about the mean quantity to add to 100 c.c. of sea-water. An exact quantity is of little importance, and it is better to add too much than too little. Keep the medusae in motion whilst the formalin is being added, and for at least two minutes after. The stirring is very important, as it produces an even distribution of the formalin in the sea-water, and the motion keeps the medusae off the bottom, and allows them to die in a fairly well-expanded condition. Some species are more liable to contract than others, and much depends upon the condition of the specimens.

The medusae may be left at the bottom of the vessel for a few hours, and then they should be transferred to a stronger solution of formalin—about 5 per cent.—and finally stored away in formalin 10 per cent.

To obtain medusae in a good state of expansion, and with tentacles stretched out, it is necessary to use an anaesthetic. This gives a little extra trouble, but the results are well worth the effort when really nice specimens are wanted. One of the best anaesthetics is hydrochloride of cocaine, in either a 1 per cent. or a 2 per cent. solution.

Place the medusae in a small glass vessel with just sufficient sea-water for them to swim in. After they have expanded, add a little cocaine (about 3 c.c. of 1 per cent. for every 100 c.c. of sea-water), and stir gently with a glass

rod to mix the cocaine with the sea-water. If the medusae at the end of about ten to fifteen minutes have their tentacles expanded, and do not contract when touched with a glass rod, no more cocaine need be added; but if still active, add a little more cocaine, and repeat the stirring process. It is better to add about half the cocaine at first, and gradually to increase the quantity, than to give the whole dose at once. An overdose generally causes a prolonged contraction. As soon as the medusae are anaesthetized, stir them gently round and pour in the formalin solution. Keep on stirring whilst the formalin is being added, and for a minute or longer after. Specimens must not be left long in any solutions containing cocaine, as it has a softening action upon the jelly. A medusa anaesthetized with cocaine may also be killed with picric acid, corrosive sublimate, or any other good fixing solution.

Siphonophores. The belled forms (Calyconectae) are about the easiest siphonophores to preserve, and for them formalin is recommended. The stolon bearing the cormidia usually becomes contracted, but occasionally one is killed in an expanded condition. A sudden dose of picric acid is a good killing agent, as it acts very quickly. Leave the specimens in the picric for about twenty minutes, and then gradually transfer to formalin or alcohol.

The forms with a small float (Physonectae) require a considerable amount of skill, patience, and experience for their successful preservation in an expanded condition. Unless one is prepared to devote the necessary time and attention to the operation, it is far better to place the colonies of these and the other groups in formalin 5 per cent. or 10 per cent., and chance the result. When dismemberment of the colony takes place, collect the fragments and put them all into a small bottle.

For killing colonies in an expanded condition a mixture of corrosive sublimate and copper sulphate is frequently used. After the death of the colony, a few drops of nitric acid are added to prevent the formation of precipitates. Then Flemming's solution is poured in for the purpose of hardening the tissues. After about twenty-four hours in the above mixture, alcohol is introduced, just a few drops at a time, and the strength very slowly and gradually increased to 70 per cent. Nearly all the methods for the preservation of Siphonophora were published before the advent of formalin, and alcohol is always recommended. Formalin, however, has several advantages over alcohol for these delicate organisms, and should always be given a good trial.

Menthol has been used as an anaesthetic with some success. At the right moment formalin is poured in to kill. The success depends upon adding the formalin just at that moment.

The Cystonectae (Physalia, &c.) are quickly killed with a mixture of corrosive sublimate and acetic acid. Transfer to chromic acid ½ per cent. for about an hour, and then remove to dilute alcohol, and gradually increase the strength to 70 per cent. Care must be taken not to touch a living Physalia, as its stinging power is tremendous, and the pain is excruciating.

The Disconectae (Velella, Porpita, &c.) are fairly easy to preserve. Velella may be killed with picric acid or corrosive sublimate. Add, after death, a little chromic acid for hardening the tissues. Leave the specimen for about half an hour in the mixture, and then transfer to dilute alcohol after picric, but after corrosive wash well in water and then put into alcohol. Velella frequently dies fairly well expanded in formalin. Porpita is best killed with picric acid; transfer to alcohol or formalin.

Scyphomedusae are quickly killed with formalin. Make up a solution of about 5 per cent. formalin by pouring some strong formalin into sea-water. Select a vessel a little larger than the specimen, pour in the formalin solution, and place the specimen in, mouth upwards. Leave it alone for about an hour, and then add a little strong formalin and give a gentle stir up. It must not be forgotten that Scyphomedusae contain an enormous amount of watery fluid, hence the necessity for adding strong formalin to keep up the strength of the solution, which should be at least 10 per cent., before storing away the specimen. In the case of large Scyphomedusae it is best to give small doses of strong formalin at intervals of about two or three days, and to give a thorough stir up, moving the specimens about.

It is a distinct advantage, soon after killing the medusa in formalin, to pour in some chromic acid—about a 5 per cent. solution—just enough to colour the formalin. The chromic acid makes the jelly tough and more pliable, so that there is less risk of breakage when the specimens are handled for examination. The yellowish-brown colour of the chromic acid may be disregarded, because in the course of a few months the colour changes to a pale bluish-green, owing to the oxidation of the chromic acid.

The successful preservation of Scyphomedusae, especially the large ones, greatly depends upon using plenty of strong formalin.

Ctenophores are troublesome animals to preserve, because nearly every genus requires special treatment. There is, however, one general rule to be remembered—namely, that Ctenophores must not be stored away in formalin, but always in alcohol 70 per cent.

Pleurobrachia may be killed in formalin 5 per cent. in sea-water. The simplest method is to fill a large test-tube

or a tall cylindrical measuring-glass with the formalin solution and to drop the specimens in. Leave them alone until they sink to the bottom, and then remove to formalin 5 per cent. in fresh water. They may be left in formalin for a few weeks, but it is best not to delay their transference into alcohol too long. Begin with very dilute alcohol, and gradually work up to 70 per cent. strength.

Beroe may occasionally be killed in a fairly good, expanded condition by allowing it to swim in a small glass pot, with just sufficient sea-water to cover it, and then, when fully expanded, pouring in very quickly a large quantity of corrosive sublimate (saturated solution in sea-water). As soon as the specimen has become white, pour off the corrosive and add fresh water. Wash it well in several changes of water to remove the corrosive, and then transfer gradually from very weak alcohol to 70 per cent. alcohol.

Bolina dissolves up at once in formalin. The best results are obtained by killing quickly with Flemming's solution and selecting quite small specimens. Leave them in the solution for about half an hour, wash slightly in water, and transfer very gradually from very weak alcohol to 70 per cent. alcohol.

Flemming's solution is about the best killing and fixing solution for Ctenophores.

Anemones and Corals are amongst the most difficult of marine animals to preserve in an expanded state. For ordinary sea anemones, formalin, followed by formalin-spirit, is preferred. The method which is most often successful is to anaesthetize with menthol (p. 403); the process usually takes from twelve to twenty-four hours. When the creatures no longer react when touched, plunge them suddenly into formalin or formalin-spirit (see p. 397), and for several minutes inject the fixing fluid into the

mouth with a syringe or pipette, using pressure with due caution, or into hot corrosive sublimate, any one of which preserving fluids gives good results.

For 'corals', such as Caryophyllia, Alcyonium, and Gorgonia, use hot corrosive sublimate after the menthol, or 5 per cent. formalin followed by cold saturated corrosive sublimate. But a plunge into 90 per cent. spirit, not allowed to get weaker than 70 per cent., has given fair results for anatomical work.

Starfishes. Specimens required to show only external features may be preserved in 70 per cent. alcohol or in formalin. They retain their natural shape better if they are put for two or three minutes into fresh water before being placed in the preserving fluid. If the internal anatomy is to be studied, an incision should be made along the length of each arm, so as to allow the preserving fluid to enter, and the specimen be preserved in 2 per cent. chromic acid, washed in running water, and transferred to 70 per cent. alcohol; or the specimen may be placed at once in formalin-spirit, or 5 per cent. formalin, without the use of chromic acid.

Antedon. Specimens thrown flat into a shallow dish of strong spirit give good results. There should be just enough spirit to cover the specimens.

Echinoids. Echinus and similar forms may be preserved with the tube feet expanded by transferring a healthy specimen suddenly to strong acetic acid or to warm 70 per cent. alcohol. If only the internal parts are required, a hole should be made in the shell, and the specimen put at once into 70 per cent. spirit, or into formalin-spirit.

Holothurians. Specimens merely killed in spirit, and with spirit also injected by the anus, are sufficient for the purposes of the ordinary collector.

Formalin and all acids should be avoided, as it is important not to injure the calcareous plates in the skin.

But if nicely expanded specimens are desired, they should be anaesthetized in the ordinary way with menthol (about twelve hours). They will then generally remain expanded. As soon as they cease to react when the tentacles are touched, they may be transferred to 70 per cent. spirit, and at the same time injected with 90 per cent. spirit through the anus.

Polychaeta. To preserve these worms the following has proved to be the most useful general method: The worms are first placed in a vessel of clean sea-water, and 70 per cent. alcohol is added drop by drop, and mixed by gentle stirring with the sea-water. The operation is repeated every few minutes, the dose of alcohol being increased on each occasion. In the course of ten or fifteen minutes the worms will become motionless and limp, and will show no movement on being touched. They are then taken one at a time from the sea-water, and laid upon a dry glass plate, on which they are stretched out with the help of two camel-hair brushes. In this position they are killed with formalin-spirit (90 per cent. alcohol, 100 volumes; formalin 40 per cent., 5 volumes),[1] placed on them by means of one of the camel-hair brushes, only enough being used just to surround the worm, without running over the glass plate. If the worms contract or become slightly contorted when the formalin-spirit is first added, as they generally do, they should be straightened out with the brushes, and held in a suitable position until they begin to get hard. After a few minutes on the glass plate they will become sufficiently hard to be removed to a flat-bottomed dish containing formalin-spirit, in which the fixing process should be completed. In practice one may

[1] It is an advantage to use the stronger alcohol (90 per cent.) for Polychaetes.

have a considerable number of the worms on the glass plate at the same time, continually moving some to the dish of formalin-spirit, and taking fresh ones from the sea-water.

After being in the flat-bottomed dish for some hours, the worms may be transferred to tubes, and stored permanently in formalin-spirit.

Aphrodite and Hermione are killed well extended if placed in fresh water for ten or fifteen minutes.

For histological work, Bouin's fluid, Hermann's fluid, Flemming's fluid, and corrosive sublimate-acetic acid mixture, give good results. The worms should be killed by adding alcohol to the sea-water, and the first stage of hardening should be carried out on a dry glass plate in the way above described, Bouin's fluid, &c., being used instead of formalin-spirit. For their further treatment, see pp. 399–401.

We are indebted to Mr. R. T. Leiper for the following notes on the preservation of parasitic worms.

(*a*) *Preservation*

Nematoda. The worms are washed by shaking in 1 per cent. saline solution, killed by plunging each separately into a quantity of 70 per cent. alcohol that has been heated to its boiling-point, and stored in fresh 70 per cent. alcohol for examination. If this method is properly applied the worms should die in an extended and straightened position.

Trematoda. Clean by shaking in a test-tube half full of 1 per cent. saline solution; the dirty liquid having been decanted off, one-third of the tube is filled again with 1 per cent. saline, in which the worms are shaken vigorously, and an equal quantity of saturated $HgCl_2$ quickly added—the vigorous shaking being continued for several minutes thereafter. This treatment should kill and fix the flukes in an extended position. The parasites may be left in the fixing fluid several days, or they may be transferred immediately to water, washed for twelve hours, and finally stored in 70 per cent. alcohol.

Large trematodes, sections of which are required for diagnosis, may be treated in the same way, or formalin 10 per cent. may be substituted for the corrosive sublimate as fixing reagent, and a weaker strength, say 3 per cent., used as a storing medium.

Cestoda. The strobila are washed gently in 1 per cent. saline, fixed in a solution containing equal parts of saturated corrosive sublimate and 70 per cent. alcohol, to which a few drops of glacial acetic acid have been added—the whole heated to about 50° C. The tapeworms remain in the fixing fluid until it is cold; they are then washed in running water for twelve hours, and transferred to 70 per cent. alcohol.

(*b*) *Examination*

Nematoda. The worms, preserved in 70 per cent. alcohol, are transferred to a solution made up of 70 per cent. alcohol containing 5 per cent. glycerine. This solution is then placed on a warm plate or incubator at about 60° C., and allowed to evaporate slowly. The process takes about twenty-four hours, or even two days, to complete, by which time the alcohol and water will have passed off as vapour, leaving the worms in viscid—almost pure—glycerine. They may then be examined in pure glycerine, or mounted in glycerine jelly as permanent slide-preparations.

For rapid examination the specimens after fixation in boiling 70 per cent. may be transferred to absolute alcohol for thirty minutes, and then cleaned in 'white' creosote.

By this method the details of all small nematodes may be seen perfectly. In the case of large forms, like some of the Ascaridae, the details of internal anatomy can be made out by transference from 70 per cent. alcohol to spirit, and thence to creosote. The worms should be examined in creosote, and then returned, for keeping, to 70 per cent. alcohol.

Trematoda. Small forms are examined whole, after clearing in creosote, being transferred thereto from spirit.

For examination of large opaque forms sections are necessary; for embedding, rapid transference from formalin through acetone direct to paraffin is suitable.

When dehydration is complete, which may be tested by transference to aniline oil (if this is done the specimen must be returned to acetone), transfer to a warm mixture of acetone and paraffin, when infiltration is rapidly effected under an exhaust pump.

If it is desired to stain whole flukes they should be left several days in very weak haematoxylin, and then differentiated with weak acid.

Cestoda. Stain by immersion in weak haematoxylin after fixing, or by direct immersion whilst alive in weak haematoxylin and weak glycerine. Differentiate with acid after several days, and mount according to general methods.

Copepoda, Ostracoda, &c. Preserve in 5 per cent. formalin in sea-water. They may either be kept permanently in this fluid, or be subsequently transferred to 70 per cent. alcohol, the latter being perhaps the better plan.

For histological work, Hermann's fluid or corrosive sublimate give good results.

Amphipoda and Isopoda, Cirrhipedia, &c. For general purposes these may all be put directly into 70 per cent. alcohol. Neutral formalin 5 per cent. may also be used.

Decapoda. Crabs, shrimps, prawns, &c., should be killed in fresh water, and then put into 70 per cent. alcohol into which a little glycerine has been added to keep the joints supple. If put directly into alcohol, most of the crabs are liable to throw off some of their legs. In the case of crabs and lobsters larger than (say) half a crown, it is advisable to slit up the membrane at the back of the carapace with a sharp knife, so as to let the alcohol get into the interior.

For histological work on all Crustacea any of the ordinary preserving fluids may be used, but they do not easily penetrate the chitinous coat. Hot corrosive sublimate probably gives the best result. Excellent results may, however, be obtained with Flemming's, Hermann's, and other fluids, if a specimen can be obtained which has only just moulted and is in the 'soft' condition. The great secret of obtaining good histological preparations of Crustacea is to use only specimens in this condition, as

not only is the preservation very much improved, but the making of sections becomes easy, instead of wellnigh impossible.

Polyzoa. For general purposes Polyzoa are best put directly into 70 per cent. alcohol. This enables the soft parts to be examined, or admits of the specimens being easily dried for examination of the calcareous skeleton. If it is wished to preserve the colour of a colony, it should be washed with fresh water to remove the salt, and then dried in the air, without the use of spirit.

Bowerbankia-like forms and Ctenostomes in general may be preserved in formalin.

If it is desired to preserve material with the polypites expanded, first anaesthetize with cocaine or stovaine, and then kill rapidly with formalin. In the case of calcareous material, transfer at once from the formalin to 70 per cent. alcohol. Other reagents may be used instead of formalin, but are best employed hot.

Nudibranchiata. Kill by plunging suddenly into glacial acetic acid. Transfer at once to weak and then to 70 per cent. alcohol, or transfer at once to 5 per cent. formalin. The larger forms, such as Archidoris tuberculata, are best killed with menthol or anaesthetized by the alcohol method, and preserved in formalin-spirit.

Gastropoda and Lamellibranchiata. These may often be killed expanded by putting crystals of menthol on the surface of the sea-water containing them. Alcohol, added very slowly to the sea-water, will sometimes produce the same result, but is very uncertain. After killing, any of the ordinary preserving fluids may be used, formalin-spirit being good for general purposes. In the case of lamellibranchs, it is a good plan to slip a wedge of wood or cork between the open valves, to prevent them closing again.

Simple and Compound Ascidians. Anaesthetize with

menthol, and preserve in 2 per cent. chromic acid solution, or in any of the ordinary preserving fluids.

The free-swimming Tunicates (Salpa, Doliolum, Pyrosoma, &c.) are easily preserved by simply placing them in formalin 10 per cent. Allow them to soak for a day or two, and then increase the strength of the formalin. The addition of a very small quantity of chromic acid 1 per cent. solution to the formalin is an advantage, as it helps to harden the gelatinous test.

Salpae arranged in chains frequently become isolated when only formalin is used. A mixture of corrosive sublimate and acetic (10 c.c. glacial acetic and 90 c.c. corrosive sublimate) or Bouin's fluid is very good for their retention in chains. Pour a large quantity of the mixture into the vessel containing the Salps. Wash well in water before transferring to alcohol or formalin.

Doliolum and other very small Salps may be killed by dropping them into picric acid, but simple formalin acts very well.

Fishes. The best preservatives for fishes are: (1) Five per cent. formalin (say 2 per cent. formaldehyde); (2) 70 per cent. alcohol; and (3) 70 per cent. alcohol to which 5 per cent. formalin has been added.

For preserving for a short time only there is little doubt that 5 per cent. formalin is the best, as both the form and colour are better retained. After a considerable time, however, the specimens deteriorate.

Holt and Byrne recommend preserving first in 5 per cent. formalin (40 per cent. strength), and then transferring to alcohol, or after a few weeks to equal parts 95 per cent. alcohol and formalin 5 per cent.

Fish intended specially for dissection are best preserved in formol-alcohol.

The best way of preserving the colours of fish is to

preserve in 5 per cent. neutral formalin, and keep the specimens in the dark. But even under these conditions the colours last a few months only.

Fish Eggs and Larvae. These are best preserved in 5 per cent. formalin. They retain both form and size well in this fluid, whereas in alcohol they shrink considerably.

Sublimate with acetic, Bouin's fluid, and saturated sublimate (90 parts) with formalin (10 parts) are all good for fixing fish larvae for histological purposes.

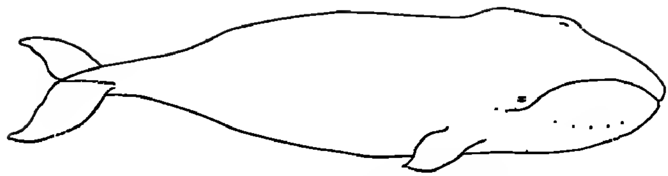


FIG. 217. The Greenland whale

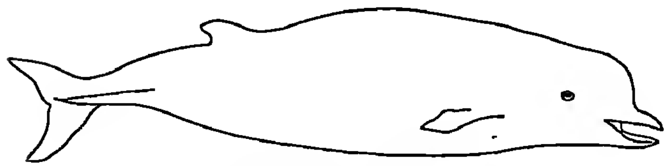


FIG. 218. The Bottlenose

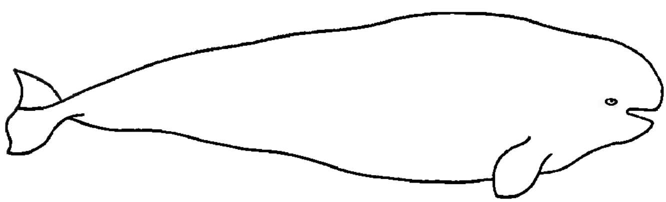


FIG. 219. The White whale, or Beluga

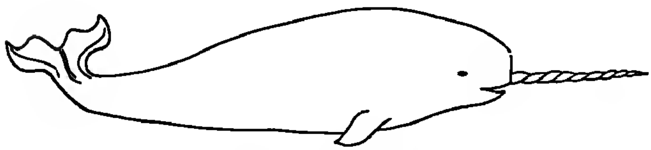


FIG. 220. The Narwhal

XII

WHALES, SEALS, AND SEA-SERPENTS

BY D'ARCY WENTWORTH THOMPSON

I. *Whales*

WHALES and dolphins of all kinds form, in our modern classification, the group Cetacea; for so we have learnt to use an ancient word which Greek mariners used of all manner of great sea-monsters, shark or tunny or whale. And the Cetacea form, for us, one order of the mammals —that is to say, of those warm-blooded vertebrate animals that suckle their young at the breast. Behind these simple facts we hide a deal of ignorance; for as to what the mammalia are, how their several orders are related to one another, and in what way or ways they have been evolved from Reptiles or other lower vertebrates, of all these things we have neither definite knowledge nor plausible and accepted hypothesis. But whether or no, the Cetacea are mammals and not fish. The hairy coat of the ordinary mammal has disappeared; for, wet and matted, without its entanglement of air, the hairy covering would wholly cease to act as an efficient non-conductor of heat. Its part is played by the thick layer of blubber under the smooth skin, and just a few hairs remain about the lips, especially in the young, to remind us of the former presence of a hairy coat. The blood is copious and hot, and in various parts of the creature's body complex networks of small bloodvessels, the 'retia mirabilia', hold the plentiful supply. The hind-legs have disappeared to outward view; but within the body, remnants of the pelvis, thigh-bones, and sometimes even of the leg-bones, are still to be found. The fore-limbs are in many ways peculiar: the arm-bone is extremely short, sometimes almost as broad as it is long;

its great round head moves freely on the shoulder-blade, but elsewhere the limb has little or no freedom, the fingers being bound together by sinew and skin, and the flipper moving all of a piece. The flippers, usually small, are sometimes of great length, as in the Caaing whale and the Humpback; it is not by their means that the creature swims, but by the sculling action of the flukes of the mighty tail, the flippers in all probability maintaining equilibrium in the water, and keeping the animal on an even keel. While all other mammals soever have the same number of joints that we have in fingers and toes, these numbers are always exceeded in the whales; and sometimes (Globiocephalus) the finger has twenty joints or more, so that the limb has a great resemblance (however that may have been brought about) to the many-jointed paddle of Ichthyosaurus and the other allied extinct marine sea-dragons. In every curve of the whale's body we seem to see an adaptation of form to motion in water; even where we have, as in the Sperm and Greenland whales, a great blunt head behind which the body tapers away, it can be shown that, as in the not very differently shaped hull of an old Dutch schooner, such a conformation is on lines directly suited to speedy progress.

While all the Cetacea are so far alike as to be easily distinguished from other animals, yet there are great differences between one whale and another; and not the least of these differences are in respect of size. For some of the smaller dolphins are only about a yard long, while many species of whales attain a length of 50, 60, or 70 ft.; and the largest of all, the Blue whale, or Sibbald's Rorqual, reaches 100 ft. in length, and even a little more. We may make a rough estimate of the weight of one of these gigantic creatures by remembering the simple rule that in bodies of similar shape the bulk or

weight will vary as the cubes of the linear dimensions. I find that a foetal Rorqual, just a foot long, weighs 1 lb. 6 oz. It follows that a whale of 40 ft. long should weigh 40^3, or 64,000 times as much as the said foetus, or somewhere about 38 tons; a whale 85 ft. long would, on the same proportion, weigh close upon ten times as much, somewhere about 370 tons; and a whale 100 ft. long would weigh about 600 tons.

The Cetacea at present existing are divided by naturalists into two great groups—the Whalebone whales and the Toothed whales, with which latter the dolphins and porpoises are included.

The Whalebone whales are technically known as the Mystacoceti, which literally means the 'Moustache whales', but which name, more than two thousand years ago, was already corrupted and punned upon into *μῦς τὸ κῆτος*, the 'Mouse-whale' or Whale-mouse'. There are two families of Whalebone whales, the Balaenidae and the Balaenopteridae; the former including the so-called 'Right whales', and the latter the 'Rorquals' or 'Finners' and the 'Humpbacked whale'. The chief difference between the two families is one of degree, the whalebone in the former being very long, and in the latter comparatively short; naturally the mouth in the former is enormous, and the head huge in proportion, so that the animal's body looks short and small behind its gigantic head. The Right whales are by no means so large as the largest of the Rorquals, and 45 to 50 ft. is a large size for a Greenland whale. Such a whale has whalebone of 11 to 12 ft. in length, and whalebone of 13 ft. in length is about the largest known, at least of recent years. Owing perhaps to the comparative shortness of the body, the Right whales have no dorsal fin, while such a fin is always present (though sometimes small) in the longer bodied Rorquals.

Lastly, and this is a useful character for the recognition of the diverse kinds at sea, the Rorquals disappear gradually from view, seldom or never diving tail up, while the Right whales dive more suddenly, the great head plunging down while the flukes of the tail are tossed upwards.

Among the Balaenidae several different species of Balaena, or Right whale, have been described, and naturalists are not yet agreed as to their number or distinctive characters. In the North Atlantic region we have certainly two, Balaena mysticetus, the Greenland whale, and B. glacialis or biscayensis, the Biscayan whale, or Nordkaper, to which latter our whaling captains sometimes restrict the name Right whale.

The Greenland whale is the true Polar whale, and is never found very far from the edge of the ice (Fig. 217); it is, unfortunately, on the high road to extinction. In the seventeenth century it was the object of an immense fishery, shared by Holland, England, and France, and the great Dutch settlement of Smeerenberg, in Spitzbergen, employed at one time (about the year 1680) 260 ships and over 14,000 men. These were the great days of the Arctic whale fishery. Oil was the great object of the trade, for whalebone was as yet of little value; the cities of Europe were lighted with whale-oil, and the slaughter was prodigious. Before long the whales became very scarce in the neighbourhood of Spitzbergen, where the Greenland whale appears to be now totally extinct; it appears also to be nowadays absent from the east side of Greenland, and it is not known from the north coast of Asia, eastward of Spitzbergen, until we get very near to Bering Straits. The British whale fishers have at all times chiefly resorted to Davis Straits. Up to the beginning of last century almost every east coast port sent out its whalers, and between 1788 and 1879, 8,415 whales were brought into

Scottish harbours. But the fleet dwindled to three or four staunch old ships, sailing from Dundee, some half-dozen whales or less formed the shrunken catch, and shortly before the great war there came an end to this old and adventurous trade. Another fleet sailed out of San Francisco to the Sea of Ochotsk and through the Straits to Point Barrow and Herschel Island, finding whales plentiful enough long after they had grown scarce on the eastern side; in one year (1893) the Frisco fleet brought home 293 whales. It had an evil repute for bullying mates, for crimps and shanghaied crews; now, for better for worse, it has passed utterly away. The vast catches of the Finner whales, of which we shall speak directly, so lowered the price of oil and still more of 'bone' that the Arctic fishery came to an unwilling end, leaving but a very scanty remnant of the great 'fish'.

Some naturalists are inclined to think that we have, or had, three great tribes or races of the Greenland whale, appertaining respectively to Spitzbergen, to Davis Straits and Baffin's Bay, and to the neighbourhood of Bering Straits. Much has been written about the annual migrations of the whale, southward in autumn and northward with the retreating ice. In the Davis Straits Fishery the old males come southward in early winter along the west coast of Greenland, the females and young animals taking a different course in the direction of Hudson Straits. In spring the males go westward from the neighbourhood of Disco, and meet the females somewhere about Baffin's Bay. When the ice in Lancaster Sound breaks up, the whales pass northward, and their chief haunt in summer is in the neighbourhood of Prince Regent's Inlet.

The Greenland whale is deep bluish-black in colour over the back, and grey upon the belly; the neck and throat are white.

Long before the Arctic whale fishery began, a very ancient and important fishery was carried on from the Basque cities. Of this fishery records are said to exist as far back as the ninth century, and when other nations began the pursuit of the whale it was Basque sailors who taught them the trade and accompanied them as harpooners. 'Harpoon' itself is said to be a Basque word. This Basque fishery was very flourishing in the sixteenth century, and only became extinct in the beginning of the eighteenth. We owe to the great surgeon, Ambrose Paré, an account of the fishery at its chief seat, Biarritz.

The Biscayan whale differs from the Polar or Greenland whale in several minor characters, but the chief difference is in the smaller head, and the correspondingly shorter whalebone; this does not exceed 7 ft. in length, and is of a coarser quality than that of the Greenland whale. For a long time naturalists supposed that this species was entirely extinct. In recent years, however, it has been captured in considerable numbers at several of the many whaling stations that have been established on our own coasts and elsewhere around the North Atlantic. It appears to be not infrequent in Iceland, and lately many examples have been got at the whaling station of Bunavenader in the Hebrides. This whale has also been got in the Mediterranean, and it is known from as far off as the Azores, Bermuda, and Bear Island in the neighbourhood of Spitzbergen. It is accordingly a great wanderer: and indeed, its wanderings are greater still, for there is little or no real distinction between this species of the North Atlantic and the so-called B. australis of the Southern Ocean. This latter whale was the object of an immense American fishery in the beginning of the nineteenth century, and from 1804 to 1817 no less than 193,522

'southern Right whales' are said to have been taken by their fleet. This great slaughter led so nearly to its extermination, that several Antarctic expeditions, including a small fleet of Dundee whalers sent out in 1892, failed to rediscover it; and it is very seldom seen by the many whalers at work in the southern seas, of whom we shall speak presently. In the northern half of the Pacific Ocean there is another Right whale, the so-called B. japonica, hunted from time immemorial by the Japanese, and in late years also by the Americans and the Russians. Its wanderings appear to be both wide and regular, from the Sea of Ochotsk through the 'Kadiak Ground' off the Alaskan coast, southward to Oregon. Scammon gives a vivid account of the whale fishery in these seas. Here again the specific distinctness of this whale is by no means certain, and we may take it that it is at least very closely akin to our Biscayan whale. It is at all times a difficult matter to identify with certainty the whales caught by the whale fishers, save in those cases where the whales are 'flensed' ashore, under circumstances where bones and other specimens are likely to be collected and preserved. Thus some of the Dundee whaling captains are of opinion that any Right whales which they occasionally get to the eastward of Greenland belong, not to the true Greenland whale or Bowhead, but to what they call the Right whale, and we call the Biscayan whale. Indeed, it is an open question what species was the chief object of the great Spitzbergen fishery, and I am inclined to think it is not at all unlikely that the Atlantic or Biscayan whale formed a great part of the catch.

The family Mystacoceti contains one other species very distinct from the rest; this is the Pigmy whale (Neobalaena marginata), a rare animal known only from the South Australian and New Zealand seas. It is but little known,

and appears to be a link between the present family and the next; it is only about 16 ft. long.

The Balaenopteridae, including the Rorquals or Finner whales and a few others, are Whalebone whales of large size, resembling the former family in general structure and habits, but with shorter whalebone and smaller heads; there is a dorsal fin, and the skin of the throat is curiously pleated or furrowed in long regular grooves. All the great whales that come ashore from time to time upon our coasts belong to this family. A curious study of their occurrences on the continental coasts of the North Sea might be made in the seaport towns of Germany, Holland, and Denmark, where it was for centuries the custom to record the stranding of a whale by a commemorative picture hung in the Rathhaus or Council Chamber.[1] Till recent years the whales of this family were immune from persecution, but it is very different nowadays. About forty years ago a Norwegian sea-captain, Svend Foyn, began a fishery for these whales off the north coast of Finmark. They yield an abundance of oil, their bones make excellent manure, and the flesh at first was dried, ground to powder, and used for manure or cattle food. Nowadays the dreadful waste involved is in part abated; the oil is 'cracked' to yield edible fats, meat-extract is prepared from the 'beef', and sometimes (as for instance in Oslo) the beef itself finds a ready market in the butchers' shops. Svend Foyn made a fortune, and laid the foundations of a great industry. Political reasons led towards the end of the nineteenth century to the closure of the Norwegian fishery, the local fishermen asserting that the slaughter of the whales diminished their catch of fish; but the Norwegian

[1] Since this was first written Mr. Van Deinse of Rotterdam has compiled a list of 38 Sperm-whales stranded on the Dutch coasts since 1531, and a more general list of Finner-whales stranded in the North Sea since 1306.

whale fishers carried their trade elsewhere, to Faroe, Iceland, Scotland, Newfoundland, and later on to a number of stations in the Southern Ocean, the Falklands, South Georgia, South Orkney, and elsewhere. The method of fishing is everywhere the same, by means of small steamers armed with a powerful harpoon-gun. The whales are usually towed ashore, and their carcasses rapidly disposed of with the aid of elaborate machinery; but of late years the station ashore is sometimes dispensed with, and large steamers fitted up as 'floating factories' are employed instead.

Strange to say, the harpoon-gun was invented a hundred years before Svend Foyn's time, by an Irishman in Donegal. Two brothers, Andrew and Thomas Nesbit, of Killibegs, fished for whales on that coast about the year 1759, reviving a fishery which two English naval officers had started a quarter of a century before; and Thomas, we are told, 'in order to give force to the harpoon, and also to the lances which are discharged at the fish every time he rises after the harpoon has entered, contrived to discharge both the harpoon and the lance from a swivel-gun; which succeeded so well, that in the year 1762 the company killed three whales, two of which were between 60 and 70 ft. long, and the other above 50; and in 1763, they have killed two whales of a large size, which is more than many have done that have been fitted out for Greenland, at a vast expense'.[1] This venture failed at length, and was forgotten; the fact is, it was the explosive bullet combined with the harpoon-gun which made Svend Foyn's invention a success.

The following table shows the catch in Scotland in recent years:

[1] From Captain Thomas Brown's edition of Goldsmith's *History of Animated Nature*, 1835, vol. iii, p. 469.

WHALES LANDED AT SCOTTISH WHALING STATIONS

	1904–14	1920	1921	1922	1923	1924	1925	1926	Per cent.
Finner	3672	250	—	228	313	357	370	358	67 2
Sei	1802	179	—	42	10	52	13	17	25 6
Blue whale	181	45	—	11	23	34	43	28	4 4
Humpback	53	—	—	—	—	1	—	1	0 7
Sperm	53	—	—	—	—	5	9	4	0 9
Right whale (Nordkaper)	97	—	—	—	—	—	—	—	1 2
									100 0

Norwegian whalers have fished at Shetland and in the Lewes during seventeen seasons since 1904, and their total catch has been over 8,000 whales. But that large number, which would have seemed vast and all but incredible five-and-twenty years ago, is insignificant compared to the prodigious catches made elsewhere, and especially in the South Georgian fishery. There we all but exterminated the teeming herds of fur-seals a hundred years ago, and neither more nor less ruthlessly do the whalers now hunt down the Finner and the Humpback whales—which species are identical, or to all intents and purposes identical—with those of our northern waters. Between 1909 and 1914 the average annual catch at South Georgia was over 8,000 whales; and the war brought no interruption nor remission, for it led to increased demand and to unheard of prices. The fishery is regulated by English law, its doings are carefully watched, and an exploring ship, the *Discovery*, under Dr. Stanley Kemp, is at present investigating the southern whaling-grounds and all the conditions of the fishery; but the world calls for such vast supplies of oil, and the profits of the industry are so great, that it seems vain to hope for moderation in all this prodigious slaughter. The following

brief table shows the vast scale of the industry, which (to all practical purposes) is wholly in Norwegian hands:

WHALING IN SOUTH GEORGIA

Year	No. of boats 'whale-catchers'	Whales captured	Barrels of oil	Value £
1909–14 (average)	42	8,314	304,002	822,451
1915–16 . .	57	11,792	558.805	1,856,384
1916–17 . .	44	6,474	361,087	1,542,323
1917–18 . .	48	4,313	258,476	1,658,215
1918–19 . .	49	4,838	232,371	1,725,444
1919–20 . .	43	5,247	256,252	2,748,852
1920–21 . .	48	8,520	383,816	1,559,467
1921–22 . .	50	6,955	448,885	2,244.390
1922–23 . .	—	9,915	611,372	3,056,860
1923–24 . .	—	6,737	422,321	2,492,700

Besides all this, there are other important fishing stations in the South Shetlands, the South Orkneys, and on the African coast.[1]

B. musculus, the Finner whale, forms the bulk (68 per cent.) of the Shetland catch. This is nearly, but not quite, the largest of the Rorquals, reaching a length of over 70 ft. It feeds chiefly upon small Crustacea, especially Calanus finmarchicus. It is the commonest of the Rorquals

[1] Mr. Sigurd Risting gives the following figures (admittedly incomplete, especially in the earlier years) for the numbers of whales killed in South Georgia and the South Shetlands during the seven years from 1919/20 to 1925/6:

Blue whales	18,288
Finners	20,688
Humpbacks	1,245
Sei whales	275
Sperm whales	170
Right whales	24
Total	40,690

The small number of Right whales, compared with the enormous number of Blue whales and Finners, is very remarkable.

It is also remarkable that the relative numbers of Blue whales and Finners differs much from year to year, especially at South Georgia—there are 'Blue years' and 'Finner years'. Taking Blues and Finners together, Blues made up only 21 per cent. of the total in 1920/1; but 78 per cent. of the total in the following year.

to be stranded upon our shores. Closely allied to it is B. borealis, the Sei whale, or Rudolphi's whale. This whale, which, till the establishment of these whaling stations, was supposed to be exceedingly rare, is now found to be abundant, but it is curiously irregular in its appearance. In some years—for instance, in 1906—it nearly equalled B. musculus in the Shetland catch, while in the previous year the latter species was ten times the more numerous. The average length of this whale is a little over 40 ft. Its whalebone, though short, approaches that of the Greenland whale in fineness of texture, and is worth about £100 a ton, or four times as much as that of the common Finner.

The greatest of all the Rorquals is B. sibbaldi—the Blue whale—whose average length is about 80 ft. Scoresby speaks of one he saw killed in Davis Straits, 105 ft. long; and a huge specimen which was brought ashore at Ostende in 1827, and is said to have been 102 ft. long, is the largest and the most famous whale which ever came into the North Sea. This whale is rare at Shetland, but more abundant at Bunavenadar, where, on the other hand, the common Finner is less common than at Shetland. The Blue whale is also less plentiful at Faroe and off the coast of Finmark; it is common at Iceland and Newfoundland, and in the whaling stations of this latter island about 300 were caught in the season of 1904–5. It is not only fished in enormous numbers in the Antarctic Seas, but also on the African coast, at Durban, Walvis Bay, Saldanha Bay, and Angola.

Allied to the Rorquals is the so-called Humpback whale (Megaptera boops), distinguished by its shorter and bulkier form, and especially by its immense flippers, which are white in colour, and curiously scalloped on the edge. This whale grows to a length of about 50 ft., and

is very widely distributed. The Humpbacks of the North and South Atlantic and of the North and South Pacific are hardly distinguishable from one another as species or races; as a matter of fact, they are probably inseparable, but these whales are particularly variable, and Captain Scammon declares that he never saw two quite alike. This is a true surface-feeding whale, feeding in the North chiefly on Boreophausia, and in the Antarctic on the large southern species of Euphausia; but it does not disdain fish, especially the Arctic Lodde (Osmerus arcticus). In the north it appears chiefly in summer-time, but also sometimes in February and March. It is said to swim quietly in summer-time, but to be very restless in winter, when it approaches the coast for the purpose, so the fishermen say, of freeing itself from parasites. It is certainly the case that this whale is especially infested with barnacles, and great clusters of the large whale barnacle (Coronula balaenarum), generally clustered over in their turn with Conchoderma aurita, are always to be found upon its skin. It is said to be common about the Bermudas in February, and in the Southern Hemisphere its chief abundance is in the winter season; so it may well be that this whale crosses the line in its annual migrations. It is also one of the whales of which specimens caught on the European coasts have been found with American harpoons embedded in them. This whale was reckoned a very rare wanderer to our coasts in former times, the great Tay whale of 1883 being one of three or four known examples. But it is now caught regularly in moderate numbers both at Shetland and the Hebrides, where together twelve individuals were killed in 1909. In March 1881 it is recorded that the Varanger Fjord, in the north of Norway, was 'boiling' with these Humpback whales.

The Humpback was caught in very large numbers at

South Georgia in the early years of the fishery; but the catch soon diminished, and a like diminution is said to have occurred in the South African fishery also. The following remarkable figures are taken (in round numbers) from the Interdepartmental Committee's Report:

PERCENTAGE CATCH OF WHALES AT SOUTH GEORGIA

	1910–11	1911–12	1912–13	1913–14	1914–15	1915–16	1916–17
Humpback	97	91	54	19	16	23	9
Finner	2	5	41	56	37	34	37
Blue whale	1	4	5	26	47	43	53

And this table we may continue, as follows, from Mr. Sigurd Risting's statistics:

	1919–20	1920–21	1921–22	1922–23	1923–24	1924–25	1925–
Humpback	3·0	2·5	0·0	7·6	3·4	3·7	3·0
Finner	60	75	21	31	37	38	73
Blue Whale	34	20	75	60	53	58	24

On the Pacific coast of America there is yet another large whalebone whale, reaching 50 ft. or so, the Californian Grey whale (Rachianectes glaucus). This whale was plentiful some fifty years ago off the coast of California and Oregon, where it was hunted from the shore, but as usual the hunt persisted till the whales were all but gone. The same whale is fished by the Japanese off the Corean coast, where they call it the Devil Fish: and the Vega Expedition of 1925 captured a whole shoal of them at Kamchatka.

Whatever else it may have done, the wholesale slaughter of the modern whale-fishery, it has added a good deal to our knowledge. For in many or most cases careful record is kept of the whales caught; and what we made shift to learn in former days from an occasional stranded whale, we can now study by the powerful method of statistical

averages. The dimensions of the several species and of their two sexes, the proportions of the sexes (which differ much from one species to another), the periods of gestation, the seasons of parturition, the orderly migrations of the whales and the seasons of their greatest abundance here and there—all these are matters concerning which we get plentiful information from the records of the fishery.

So much for the family of Whalebone whales, from which we now pass to the Odontoceti, or toothed whales. These entirely lack the whalebone fringes, and are provided with teeth, which vary greatly in number, disposition, and size. Typically (that is to say, in the ordinary dolphins), they are very numerous, small and conical—all alike, without distinction of molars, canines, &c., set in imperfectly formed sockets, or practically open grooves, along the edge of the jaw. There is but a single set, no milk-teeth being displaced by the permanent dentition. In short, in a variety of ways the teeth of the dolphins are more like those of the reptiles than of ordinary mammals.

The greatest of the toothed whales is the Sperm whale or Cachalot (Physeter macrocephalus), which attains a length of over 60 ft., or, according to some statements, as much as 80 ft. The gigantic head and straight blunt forehead give this whale a characteristic appearance, the head being swollen out by a huge mass of the peculiar fatty substance known as 'spermaceti'. The teeth are large, and limited to the lower jaw. The blow-hole stands a little to one side at the very front of the head. This whale is absolutely cosmopolitan, its chief haunts being in the warmer seas. The jaw is so overhung by the great head that, like a shark, it has to turn over on its back to bite. Its food, like several of the other toothed whales, consists mainly of

cuttle-fishes, and several gigantic species of the latter are only known from their half-digested remains found within the stomach of the whale. The late Prince of Monaco took great interest in this curious method of studying these rare oceanic cuttle-fish. The Sperm whale on its wanderings comes now and then to our own coasts. It is seldom caught at Shetland, but the Hebridean whaling-station got no less than seven individuals in 1909; and it is a very curious circumstance that all the sperm whales captured on our Scottish whaling-stations are found to be males, and males of moderate size. The old bulls fight for possession of the cows on the breeding-grounds in southern altitudes, and the young males, defeated and driven from their haunts, wander over the ocean. They get into the great warm ocean currents, and so, in no inconsiderable numbers, reach our coasts and perish there. Towards the end of the eighteenth century London sent out a considerable fleet to the sperm-whale fishing, numbering at one time as many as seventy-five vessels, and it was British whalers who opened up the remote whaling-grounds of the Pacific and Indian Oceans. But still earlier the Nantucket whalers had pursued the Sperm whale, and the fishery long remained in American hands; the reader is doubtless familiar with Mr. Frank Bullen's graphic descriptions in 'The Cruise of the *Cachalot*'. Besides the oil (which is much more valuable than that of any other whales) and spermaceti, the Sperm whale yields the very curious product known as 'ambergris'. This is a concretion of the intestines, is usually intermixed with cuttle-fish beaks, and is probably a product of the digested cuttle-fish. It is one of the most costly articles in commerce. It has but little perfume of its own, but it is a constituent of all the finer scents, for it seems to have some curious property of blending and

improving the perfumes with which it is mixed. Now and then large masses of it have been found cast ashore or floating in the ocean.

There is a curious and rare species in the Southern Ocean, called the Pigmy Sperm whale (Kogia), a miniature—some 15 ft. long—of its great ally.

There comes next a subfamily, known as the Ziphioid or Beaked whales. These are whales of moderate size, and, like the Sperm whale, make their diet of cuttle-fish. One species, the Bottle-nosed whale (Fig. 218) or Hyperoödon, is the object of a fishery first started by Capt. Grey of Peterhead, but which fell into Norwegian hands and was prosecuted by small vessels from Labrador to Nova Zembla. The Bottle-nosed whales go about in small herds, and, like the other Ziphioids, the male and female are recognizably different, the male having greatly enlarged crests upon its skull. The oil contains a considerable percentage of spermaceti, and the skin makes an excellent leather, supplying a great deal of what are known as porpoise leather boots. This whale can leap right out of the water, and is said to turn its head from side to side while in the air. The other Ziphioids (Mesoplodon, Berardius, and Ziphius) are all more or less rare forms which have been found in various parts of the world, but in such small numbers that the number and character of the species are still in dispute. Mesoplodon and Ziphius have both occurred on our own coasts, and it appears to be a common or general rule that when an individual comes ashore, its mate will before very long be found stranded in the near neighbourhood.

There remains the family of the Dolphins, which includes a number of very diverse forms. The largest is the Great Killer-whale, or Grampus (Orca gladiator), an animal reaching some 30 ft. long. This whale is easily

recognized by its high curved dorsal fin. It has in each jaw ten or twelve powerful teeth. Its body is conspicuously marked with white or yellowish bands. It is a fierce, predaceous creature, attacking seals, porpoises, and the like, and even sometimes the larger whales. Eschricht says that thirteen porpoises and fourteen seals were taken from the stomach of a single individual. Three species of the dolphin family are hunted by man. The first of these is the so-called 'Ca'ing whale' (Globiocephalus melas); this whale is not large or valuable enough for an extended commerce, but is of great value to the inhabitants of Orkney and the Faroe Islands, where herds coming inshore in the summer months are surrounded by all the boats of the neighbourhood, which drive or 'ca" them with shouts and splashings to the beach. This whale, like the Sperm whale, is a feeder upon cuttle-fish.

Next we have the White whale, or Beluga. This is a northern species, especially abundant off the coasts of Labrador and Canada; it is a small whale, about 10 or 12 ft. long, and is an eater of fish, especially, it is said, of salmon (Fig. 219). Its skin, like that of Hyperoödon, is used for leather. The Dundee whalers used to bring a considerable number of White whales, chiefly from the neighbourhood of Cumberland Gulf.

Closely akin to the Beluga is that very curious creature, the Narwhal. The teeth of this whale are all absent save one, and this one, which is present only in the males, is magnified into the long, twisted tusk (Fig. 220). In the embryo, besides rudiments of the other teeth, two small tusks may always be detected, and, as a rare abnormality, both of these occasionally grow to a full size. One such two-horned Narwhal, in the museum at Hamburg, is one of the oldest natural history specimens in the museums of the world. The Narwhal is exclusively Arctic, but has now

and then wandered as far as our own coasts. It is valuable only for its ivory, which brings a fair price. Some five-and-forty years ago the price was extremely high, and I used to be told that the commodity had been 'cornered' by a petty Indian rajah, who stockaded his palace all round with a fence of the tusks, confident in their exceptional virtue against the Evil Eye. Some of my readers may remember the fine tusk in the Cluny Museum, which was one of the treasures of Charlemagne, and which had been sent him by an Eastern potentate as the horn of a Unicorn.

There is but little difference between the porpoises and the true dolphins, the chief being that the teeth of the latter are pointed, while those of the former have flattened, spade-shaped crowns. The porpoise is the commonest of all our native Cetacea, and is very frequently caught in the fishermen's nets. It comes far up our rivers, and has been seen in the Seine at Paris. Its flesh was an old-time dainty, and in this respect it is not exceptional, for the flesh of the larger whales is extremely good eating. I once saw a very young porpoise taken out of the stomach of a very large cod.

The dolphins include several genera and many species, of which it is impossible to treat within the short limits of this article: neither, with any amount of description, would it be often possible for the traveller to identify the many dolphins which he sees tumbling and leaping alongside his ship, with whose course it gives them no trouble to keep pace. The Common Dolphin (Delphinus delphis) is particularly abundant in the Mediterranean, and its representations on Greek coins and in medieval heraldry, though sometimes fanciful enough, are by no means unlike the glimpse we catch of it as it flings itself out of the sea. The White-beaked Dolphins (Lagenorhynchus) are

also not very uncommon visitors to our coasts. One which I once found in Galway Bay was streaked and scored all over with what seemed to be traces of an encounter with some great cuttle-fish; and similar markings, ascribed to the same cause, have been seen by others both on these dolphins and on some of the Ziphioid whales.

A few rare and curious Cetaceans inhabit rivers. There is a genus of dolphins called Sotalia, of which one species inhabits the Cameroon River (where it is said to feed, alone of all whales, upon a vegetable diet); another lives in China, in the Amoy River; and a third in the rivers and bays of the Atlantic coast of South America. The last is very common at Rio de Janeiro, where it is protected by superstition, having the reputation of being friendly to man, and of bringing home for burial the bodies of the drowned.

Then, lastly, there are three other river-dwelling dolphins, long-snouted, many-toothed, and possessing several curious characters—among others, a separation of the cervical vertebrae, and consequent flexibility of neck, which is found in no other Cetaceans. These three genera constitute a separate family, the Platanistidae. The first of these is Platanista gangetica, the 'Susu' of the Ganges; it inhabits the Ganges and the Indus, going far up both rivers, and grubbing in the mud for food with its long snout. The next genus, Inia, inhabits the Amazons; its colour is in the main pink, with many curious variations. It is said to be dangerous to man, and the Sotalia, already alluded to, is said to defend the swimmer against its attacks. The last genus, Pontoporia, lives also in the rivers of South America, especially the Amazons and the River Plate. All of these fluviatile dolphins are rare in museums, and the traveller should not neglect to take note of their habits, and, when possible, to preserve their

remains. I am told that there is one, for instance, in the rivers of Sarawak, which is unknown to naturalists.

II. *Seals*

The seals, or Pinnipedia, constitute a suborder of the great group Carnivora, and agree with the land carnivores in the main characters of their dentition and in many other anatomical points. Awkward upon land, the seal's movements in the water are singularly graceful. Swimming by means of its broad, webbed feet (for, unlike the Cetacea, the tail is short and degenerate), aided by sinuous movements of the whole body, the creature glides rapidly along, with nothing but the head exposed; and every now and then it stops to raise its little head and stare about with its big eyes.

There are three families of seals: the Otariidae, or Eared seals; the Trichechidae, or Walruses; and the Phocidae, or True seals. Of the Phocidae we have in the North Atlantic region six species, all of which are common to both sides of the ocean, and of which all but one have been found upon the British coasts. The common Grey or Harbour seal (P. vitulina), grey with darker spots, and with a black ring round the eye, is very common on our coasts, and has a bad reputation as a poacher of salmon; it is accordingly killed in large numbers at the mouth of the Tay and other salmon rivers. It had some respite during the war, when I often counted a hundred or a hundred and fifty lying on the sand-banks, as our train passed over the Tay Bridge. It swims far up into fresh water; it never resorts to the ice, but breeds in rocky places on the shore. It grows to about 5 ft. long, or rather more. A similar and probably identical species, the so-called Leopard seal, is found in California, and in the

North Pacific; it has a close ally, Phoca pallasii. Smaller than the Grey seal, and smallest, indeed, of the family, is the little Ringed seal (P. foetida), the back of which is marked with large whitish spots. This seal is common in the Baltic, and is found now and then on our own coasts, but its proper home is in the Arctic. It is of importance to the Esquimaux for food and clothing; and it has curious habits, making for itself roofed habitations in the ice, like the 'igloos' of the Esquimaux. This is the seal whose bones are often found in our Scotch brick-clays, which are of glacial origin, and it must have been abundant on our coasts in that Arctic period. It is closely allied to the Caspian seal and to the seal which inhabits Lake Baikal; and the presence of seals in these great inland seas must be looked upon as a survival from that same epoch. The Harp seal, or Greenland seal, inhabits the edges of the drifting ice, and forms the chief part of the great Newfoundland seal fishery. The adult male is whitish in colour, with a great black belt across the shoulders and down each side, which saddle-shaped mark only becomes fully formed about the fifth year. The female is much smaller; the young are pale grey, with dark spots. Still larger than the Greenland seal is the Bearded seal (Erignathus barbatus), the Ogdook of the Esquimaux, which grows to a length of 9 or 10 ft. It is sometimes called the Square-Flipper seal, and is not uncommon in Norway. On the other side of the Atlantic it goes as far south as Labrador, and is also found both in the Greenland and the Siberian seas. The grey seal (Halichoerus gryphus) is nowhere very abundant, but comes occasionally to our own coasts. It is confined to the Atlantic region. It is light grey in colour, and the male grows to 8 or 9 ft. long. There is—or used in recent years to be—a breeding-place of this seal on the

Fro Islands, off the Trondhjem Fjord, where about 500 young were reared annually, and there are larger breeding-places near Hammerfest; but its numbers are of late years greatly diminished. Indeed, the habit of resorting, as this seal and the Greenland seal do, to a common breeding-place, instead of going in solitary pairs, as the Common seal does, would seem to be a sad disadvantage for the species in its struggle for existence with mankind. The last of the northern seals is the Hooded seal (Cystophora cristata). This is a moderately large seal, the male being about 8 ft. long, and the female 7 ft. In colour it is bluish-black, with whitish spots; but the young, as in the Harp or Greenland seal, are born white. The head is small, and bears in the male a very curious muscular sac, which is capable of inflation, and when fully stretched measures about 12 in. long by 9 in. high. This seal seems to be most abundant in the seas between Iceland and Greenland, where large numbers are killed by Norwegian sealers. It is fairly plentiful in the Spitzbergen region, but becomes scarce on the northern coasts of Europe and Asia.

In the Mediterranean one seal only occurs, the Monk seal (Monachus albiventer), and this is the seal referred to by ancient authors, from Homer downwards. It occurs also in Madeira and the Canary Islands. Very little seems to be known of the habits of this animal, and of its breeding-places, and any traveller who may have an opportunity of studying it—for instance, in the Archipelago or the Levant—would do well to take careful notes, and, if possible, photographs. A very similar and closely allied species, M. tropicalis, is found in the West Indies, where it haunts the 'Kays' or reefs of rocks round many of the islands. This seal was first mentioned by Dampier, who made a sealing voyage to the Alacrana reefs, off Yucatan, in 1675. In his time the seals were very

abundant, and much hunted, but they are now so scarce all through the West Indian region as to seem on the verge of extinction.

The true seals of the North Pacific are, as has been said, more or less closely allied to, if not identical with, those of the North Atlantic. One characteristic species, which does not occur in the Atlantic, is the Ribbon seal (Histriophoca fasciata). This seal inhabits the Kuriles, the Sea of Ochotsk, and Bering Sea, but is everywhere scarce. It is a very beautiful seal, the male being of a dark brown with a tinge of olive green, with a broad yellow band running across the neck and sides, and forming a 'saddle' similar to that of the Harp seal. This seal is much prized by the Alieuts and Esquimaux for ornamental purposes. Little or nothing is known of its habits, and it has very seldom come under the observation of European travellers.

In the Antarctic we have other species of seals, quite distinct from the northern genera. These are Stenorhynchus, the Leopard seal, a very large species; Lobodon, the crab-eating seal; Leptonyx, or Weddell's seal; and Ommatophoca, or Ross's seal, a small and rare species, with enormous eyes. Recent Antarctic expeditions have added much to our knowledge of these seals, and have brought specimens in abundance to our museums.

The last genus of the true seals is the Sea Elephant (Macrorhinus), of which one species (M. leoninus) has long been known from the Antarctic seas, and another (M. angustirostris) occurs in small and dwindling numbers off the coast of California. The sea elephants are the largest of all the seals, old bulls measuring about 20 ft. long; but the females are very much smaller. The southern sea elephants were in former times slaughtered in great numbers at Kerguelen, the Crozets, and Heard Island; and

even a hundred years ago Weddell spoke of them as nearly extinct. But they had a long spell of comparative immunity, and they have been seen of late years at South Georgia in surprising numbers. In California the northern species was still plentiful and vigorously pursued at the time of the rush to the gold-diggings in 1849 and following years.

The walruses form a family by themselves, the Trichechidae, containing one or perhaps two species, for naturalists are not agreed as to whether the Atlantic and Pacific races of this animal should be looked upon as specifically distinct or not. However this may be, it is always, so far as I know, easy to distinguish between one and the other, for the tusks of Pacific specimens are notably longer, thinner, and more convergent than are those from the Atlantic region. Unlike the seals, which are fish-eaters, the walrus lives upon 'clams'—that is to say, cockles, Myas, Mactras, and other burrowing shell-fish, the digging out of which from the sand and gravel seems to be the chief use of the great tusks. The walrus is now verging rapidly towards extinction. In the seventeenth and eighteenth centuries it was still plentiful as far south as the Gulf of St. Lawrence and the coast of Finmark. In 1852 900 were slaughtered in one day on the Thousand Isles, near Spitzbergen. By 1872 they had disappeared from southern Greenland; and the great herds which were once common throughout the Arctic seas exist no longer anywhere. The walrus has been often known to wander down to the north or west coasts of Scotland, and one came as far as the Severn about a century ago. In 1920 a walrus stayed for some days near the Skerries Light, not far from Lerwick; and in the autumn of 1926 another—or perhaps the same—was seen in the same neighbourhood. This walrus all but circumnavigated the

North Sea, being sighted several times during its voyage; it was killed at last in the neighbourhood of Gothenburg. This was a strange thing to happen, considering how far off the nearest home of the walrus must now be; but such rare stragglers have probably drifted out to sea on some great ice-floe, and made a long involuntary voyage.

The Pacific walrus is confined to a narrow stretch of coast in north-eastern Asia, and a still smaller part of the opposite American coast. Here in the early part of the nineteenth century Middendorff described them as existing in hundreds of thousands, and even between 1870 and 1880 the tusks of about 12,000 walruses were brought annually to San Francisco by the American whalers. In the Pribylov Islands, where they were still numerous in 1874, I only saw in 1897 a single dead carcass.

The Eared seals, or Otariidae, form the third and last family of the Pinnipedes. These include, in the first place, the genus Otaria, the Fur seals, so well known for the international complications to which they have given rise. The genus does not occur in the Northern Atlantic; its distribution would seem to be in the main Antarctic, from which ocean the range of one species to the Bering Sea appears to be a great but exceptional extension. Thirty years ago the Pribylov Island herds were but a shadow of their former greatness; but they are said to have increased since then considerably. The chief breeding-places of Fur seals are, or were, in the Antarctic region, at the Auckland Islands, St. Paul, and Amsterdam Islands, &c. (O. forsteri); on Robben Island and some other South African islands and coasts (O. antarctica); on various parts of the South American coast, where their haunts often give rise to the name Lobitos Islands—i.e., the islands of the sea-wolves—from Uruguay round Cape Horn to Chili and

the Galapagos (O. australis); and, chief of all, in Bering Sea and the Pribylovs, the Commander Islands, and the Kuriles (O. ursina). The several breeding-grounds in the Kuriles have been exterminated for about twenty years, and it is said that in the times of relaxed supervision during the Japanese War the Russian breeding-grounds of the Commander Islands were all but depleted. In the southern seas they are very nearly extinct, and we do not hear of the herds reappearing anywhere on their old haunts, as the sea-elephants have done at South Georgia. A Fur seal 'rookery' is one of the great sights of natural history. The bulls come ashore in spring; each gathers together a harem of as many females as he can attract to himself, and can defend by ceaseless combat from his neighbours. The bulls remain at their posts all through the season, never entering the water to feed, and by late summer are gaunt and lean. At the height of the season the long beach is a densely crowded mass of bulls, females, and pups, in noise and stench and ceaseless movement.

The genus Zalophus is allied, but differs for want of the fine fur of the Otarias. To this belongs the black 'sea lion' of the Californian coast. This animal is very graceful and docile, and is often trained for menagerie purposes. Another species of the same genus occurs on the northern coasts of Australia, and northwards to Japan. One other genus is Eumetopias, to which a single species, Steller's Sea Lion, belongs. In contrast to the Fur seals, which congregate in great 'rookeries' in a few well-known spots, these sea lions disperse in small colonies and may be seen on rocks and islands all round the North Pacific from California to the Kuriles. A protected colony on the 'seal rocks' forms one of the sights of San Francisco. They are huge, sluggish animals, sprawling with difficulty on the ground, and are generally seen basking in shallow water,

or lying motionless on the sand. I once saw very large numbers of them on the sandy beaches of Boguslov, the remarkable volcanic island near Unalaska, which first appeared within the memory of man, and which so continually changes its shape and outline that no two successive visits bring away identical views. While all these many species are well known to naturalists and well represented in museums, the traveller may still do good service by taking notes of their habits, and by photographing them under natural conditions.

III. *Sea-Serpents*

No epitome, however short, of the creatures which the mariner may hope to witness would be complete without mention of the most famous and mysterious of them all, the great 'sea-serpent'; but he is not the only 'sea-serpent'.[1]

Sea-serpents, or sea-snakes, are common enough, and constitute the family Hydrophidae. These snakes live a purely aquatic life (with one exception), and frequent the tropical parts of the Indian and Pacific Oceans. A single species lives in a fresh-water lake in the Philippines. When removed from the water they appear to be blind, and soon die. They are all virulently poisonous, and fierce in their attack; and my old master, Sir Wyville Thomson, used to tell comical tales of the panic they sometimes caused among the naturalists of the *Challenger*, when he and his colleagues were wading among the coral reefs. They are adapted in various ways for their aquatic life; the head is small and pointed; the belly is not flattened

[1] See, in particular, Henry Lee, 'Sea Monsters Unmasked', in the 'International Fisheries Exhibition Handbooks', vol. iii, pp. 321–440, London, 1884, and A. C. Oudemans, 'The Great Sea Serpent', Leiden and London, 1892.

like that of an ordinary snake, but sharp or keeled like that of a herring; the tail is flattened like that of a fish, but is at the same time prehensile, and the snake clings by means of it, like a little sea-horse, to weed or coral. The lung is of great size, and the nostrils have valves which can be tightly closed, so that, on the one hand, the creature can dive with safety, and on the other hand it may float motionless on the surface, buoyed up by its store of air. They are all viviparous. They feed on fishes, and it is said that the instant effect of their poison is to relax the whole body of the fish, so that it may be safely swallowed head foremost, its spiny fins offering no obstacle in their relaxed condition. There are many kinds of sea-snakes, belonging to several different genera. They are in most cases brilliantly coloured, often in alternate rings of black and white, sometimes adorned with green and yellow. In Indian and other eastern harbours the passenger may at times recognize their slender and gaudy shapes, swimming in the clear water. The widely distributed Hydrus platurus (or Pelamys bicolor), a rather small species, conspicuous with its yellow belly, and the much larger Distira cyanocincta, more or less annulated with black, are perhaps the oftenest seen. Many species are over a yard long, and the largest, D. grandis (from Malay and North Australia), is about 8 ft. long; specimens 12 ft. long are said to have occurred.

The sea-serpents of Aristotle and of Pliny seem to have been no more than immense eels, a family of fishes which contains many diverse, and in some cases gigantic, kinds. A famous sea-serpent that came ashore on Stronsa, in Orkney, in 1808, measured 56 ft. long, and was carefully chronicled and described in the Transactions of the Wernerian Society, was almost certainly a huge oar-fish of the genus Regalecus. Sir Everard Home, it is true,

identified the two vertebrae which alone were preserved as those of the great Basking Shark; but I have examined vertebrae of both fish, and believe that, in a more or less mutilated condition, they might well be mistaken for one another, even by an anatomist.

But the great sea-serpent is something other than these, and, whatever it may be, the many accounts of its appearance deserve a patient hearing and judicial investigation. More things than one seem to have been included under its name. It is now 'that sea-beast Leviathan, which God of all His works Created hugest that swim the ocean stream'; in Milton's account of which is mixed up the eastern tale of Sindbad the Sailor, and the great whale on which he and his comrades landed and built their fire. Again, as the Kraken of Pontoppidan (who himself, however, distinguishes between the Kraken and the true sea-serpent), it is clearly recognizable as some sort of gigantic cuttle-fish or octopus; and of the same kind was also in all probability the 'very long and frightful sea-monster' seen by the Rev. Hans Egede off Greenland in 1734. Now, though these latter denizens of the great deeps come but seldom into the hands of competent observers, yet we do know, for certain, that cuttle-fishes of enormous size exist in the various oceans. Professor Owen described one which came ashore on the Island of Achill, whose arms were 30 ft. long, and whose eyes were great globes 15 in. in diameter; and Professor Verrill has collected notes of a considerable number observed from time to time, chiefly on Newfoundland, whose arms ranged from 30 to 42 ft. in length, and whose entire length, body and arms and all, were in some cases over 50 ft. We have every reason to suppose that these few stragglers that have been stranded and measured give us but a very imperfect idea of the dimensions that may actually be attained. Again, in Japanese

pictures and carvings we have portrayed, with evident good faith and accuracy, precisely similar monsters of the cuttle-fish kind. As has been already mentioned in these pages, the Prince of Monaco on several occasions discovered in the stomach of the Sperm whale the half-digested remains of cuttle-fish, great, if not so great, as these; and it may be remembered that many stories of the sea-serpent describe it as in combat with the whale, and wrapping its long coils about the Cetacean's body. Dr. Andrew Wilson and (afterwards, and in greater detail) Mr. Henry Lee have shown that many stories of the sea-serpent might be so interpreted as to correspond to just such gigantic cuttle-fish as Owen, Verrill, and the other naturalists have proved the existence of. Thus in Hans Egede's drawing and description of his monster, with its spouting head and writhing tail, both elevated high above the surface of the sea, we seem to see the tail and one of the sinuous tentacles of a great cuttle, whose head and remaining tentacles were still submerged.

Then, again, there are many other accounts, which describe a more serpent-like animal, floating in huge coils upon the sea, such as that reported from the Indian Ocean by the Captain of H.M.S. *Daedalus* in 1848, by the officers of the barque *Pauline* in 1877, or by the Commander of the Royal Yacht *Osborne* off Sicily in the same year. Even in such accounts of the long serpent, with pointed head, swimming rapidly on a calm sea, coil after coil, Mr. Lee thinks that we have all that could well be seen from the deck of the body of a gigantic cuttle-fish, propelling itself, as its habit is, backwards by the rush of water expelled from its 'funnel', with its tail-fin simulating the serpent's head, and the wavy outline of its trunk, head, and tentacles giving the appearance of the long serpentine body.

There is a big and interesting book by Dr. Oudemans of the Hague, published in 1892, in which practically all the recorded appearances of the sea-serpent are chronicled and discussed; and Dr. Oudemans is fully convinced that underlying many of them we have a fragmentary account of something for which the cuttle-fish theory does not suffice. Since the publication of this book one of the most remarkable of all accounts of the sea-serpent has been published in the Proceedings of the Zoological Society by two eye-witnesses, Mr. E. G. B. Meade-Waldo and Mr. M. G. Nicoll, who had seen the creature from the Earl of Crawford's yacht *Valhalla*, off the coast of Brazil, on December 7, 1905. They saw a great fin about 6 ft. long standing up out of the water, and then suddenly in front of the fin a turtle-like head shot up on a long eel-like neck, of which about 6 or 8 ft. were visible. Neither the shape nor the size of the creature's body could be made out.

It is impossible to epitomize here the many other accounts of the serpent, for which the reader must be referred to Dr. Oudemans' book, and to the same source the reader must go for Dr. Oudemans' own elaborate deductions and conclusions as to what the sea-serpent really is. Suffice it here to say that he believes it to be a mammal, and to belong to the Order of the Pinnipedia, in near alliance to the eared or fur seals. We know that closely allied to these same Pinnipeds was a certain gigantic creature of the Tertiary Period—viz. Zeuglodon, or Basilosaurus, as it was first called. This great mammal, with small head, serrate teeth, long neck, and huge, more or less whale-like body, would, if we could believe it still to linger on in existing oceans, be a sea-serpent indeed.

But whether the great sea-serpent be a giant cuttle-fish or Zeuglodont mammal, or whatever else it may be, to

meet it on the high seas, with opportunity to observe, sketch, and photograph it, is something for which the seafaring traveller may reasonably keep a sharp look out, that he may see this marvel of all marvels of the great waters, and may help to transmute this old tradition into the language of prosaic science.

XIII

LOGS, NOTES, AND LABELS; ODDS AND ENDS

BY G. H. FOWLER

LOGGING, note-taking, and labelling with cold, wet fingers form at best an unpleasant task even on a fine day; they should therefore be simplified as far as possible.

All note and log-books should be bound in a glazed waterproof cloth, paged, if possible, with a white rag-paper rather than with a pulp-paper; on no account with paper of a highly sized surface. The note-books should be of a size to slip easily into a pocket; the size of log-books will depend to some extent on the handwriting, but 12 in. long by 8 in. high is a good size; if they are to be used on deck, a thin sheet of lead (about 16 metal gauge) tacked on to one cover, will prevent their being blown overboard. At night a fair copy should be made of each day's log, and the day's note-book glanced through; this often enables errors and omissions to be detected while the facts are fresh in the memory.

All labels should be placed inside the bottle, except with water samples. The paper should be selected with some care; soft wood-pulp paper should on no account be used. A 'vegetable parchment' paper is good, but any good stout rag-paper will serve the turn, if it does not rub away after soaking in water for some days. Write with a B or BB pencil, or with Wolff's Chinese ink; both of these stand years of immersion in formalin or alcohol.

Paper labels are unsatisfactory in the case of fish preserved in tanks, for the friction caused by the motion of the ship rapidly obliterates the writing. A folded label, with the writing inside, will, however, be found to stand fairly well if inserted in the mouth or under the gill cover

of the fish; better still are the soft copper labels supplied for use in gardening.

Three sample logs form pp. 462, 463, to be varied according to the character of the work proposed; the italics represent examples, not real observations. If the traveller does not intend to take detailed temperatures and water observations, everything at sea can be got on to the first pattern. The writer strongly recommends the principle of a number for each day (12.0 midnight till 11.59 p.m.) and a letter for each operation; this method simplifies labelling, and enormously facilitates reference. Any one who has worked over the Reports of some recent expeditions, in which each kind of gear and observation had its special series of numbers, will appreciate the advantages of a single series, and of a single printed table to which to refer.

The log and note-books cannot contain too many details. Their value may not be apparent at once, but some one, perhaps in twenty years' time, will find in them just the clue that he is seeking.

It is hardly possible to get out a log for the shore-collector; he must rely chiefly on his note-book. In this case also it is a good plan to take a number for each day's work, subdividing it by letters according to his fancy. The following points should always be noted.

Date; locality (**from W. side of Smith's Point for two miles westerly**); time (**12.0 noon to 6.0 p.m.**); tide (**half-ebb to L.W., springs**); weather (**cloudy and blowy, bar. 29, falling**); temperature (**of rock pools**); ground (**rocks with Fucus on the point, some pools, the rest fine sand with isolated rocks**). For animals and plants note the following kind of thing: Dry or submerged; in sand, or mud, or on rock; under rocks or stones; adhering or washed out from weed or rock; sifted out of sand; relation

GENERAL LOG

STATION 37

Date	*June 26, 1911.*	Surface temperature	*Noon, 58° F.*,[3] No. 7.[4]
Position	*50° 20′ N., 51° 39′ W.*	Surface sample	*Noon, 162.*[5]
Wind	*W.N.W. at noon; force, 3.*[1]	Bottom temperature	*37·5°*, No. *18*.[4]
Sea	*Moderate swell.*	Barometer[6]	*Noon, 29·52″.*
Sounding	*1,520 fm. by chart.*[2]	Dry bulb[6]	*63·0°.*
Bottom deposit	*Ooze.*	Wet bulb[6]	*62·5°.*

Haul	Hour	Gear	Zone	Temperature[8]	Weather[9]	Notes
37 *a*	*5.0–7.0 a.m.*	*Dredge*	*Bottom*	*37·50°*	*R.*	*2,000 fm. warp: down 40′; 36 lb. stopped 5 fm. in front of dredge.*
„ *b*	*7.30–9.30 a.m.*	*Trawl*	*Midwater*	—	*O.C.*	*Towed 1° at about 1 kt., 500 fm. warp, weighted two firebars; supposed zone 400 fm.*
„ *c*	*7.30–8.0 a.m.*	*Tow-net 26*[7]	*0 fm.*	*58·00°*	*B.*	*50 fm. warp, hauled in fast by hand, not towed.*
„ *d*	*8.0–8.30 a.m.*	*Tow-net 64*[7]	*25 fm.*	*55·50°*	*B.*	*On hand-winch; weighted 20 lb.*
„ *e*	*8.0–8.30 a.m.*	*Tow-net 64*[7]	*50 fm.*	*53·75°*	*D.C.*	
„ *f*	*10.30–11.0 a.m.*	*Horiz. closing net*	*75 fm.*	*52·00°*	*O.C.*	*Weighted 20 lb.*
„ *g*	*12.0 noon*	—	—	—	—	*Meteorological observations.*
„ *h*	*2.0–4.0 p.m.*	*Vert. closing net*	*500–400 fm.*	*40°–42·5°*	—	

1 By scale (see p. 467).
2 Or 'contour' or 'own sounding'.
3 Or Centigrade.
4 Number of thermometer.
5 Number painted on bottle.
6 Can go on meteorological log, if preferred.
7 Number of meshes per linear inch.
8 Of zone studied; add number of thermometer.
9 By scale (see p. 467).

DAILY METEOROLOGICAL LOG

Station	Date	Position D.R. or Obs.	Hour	Barometer		Thermometer				Wind		Sea	Weather	Water Sample	Fog	Remarks
				Uncorrected	Thermometer	Dry	Wet	Surface	No.	True Direction	Force					
37	*June 26, 1911*	*56° 20′ N., 51° 39′ W.*	*12 night*	*29·52*	*64·75°*	*63·5°*	*63°*	*58°*	*3*	*W.N.W.*	*3*	*Moderate swell*	*O.C.*	*162*		
		56° 31′ N., 53° 5′ W.	*4 a.m.*	*&c.*	*&c.*	*&c.*	*&c.*	*&c.*	*&c.*	*&c.*	*&c.*	*&c.*	*&c.*	*&c.*		
		&c.	*8 a.m.*													
			12 noon													
			4 p.m.													
			8 p.m.													
38	*June 27, 1911*	*56° 50′ N., 53° 35′ W.*	*12 night*													

SERIAL TEMPERATURES AND WATER SAMPLES

Station	Date	Position	Hour	Fathoms	Temperature	Number of Thermometer	Water Sample	Gear
37	*June 26, 1911*	*56° 20′ N., 51° 39′ W.*	*12 noon*	*0*	*58·00°*	*3*	*201*	*Bucket*
				25	*55·50°*	*7*	*202*	*Petterss*
				50	*53·75°*	*8*	*203*	*Monac*
				75	*52·00°*	*11*	*204*	*&c.*
				&c.	*&c.*	*&c.*	*&c.*	

to H.W. and L.W. marks, &c. A specimen by itself has very little value; a specimen with full notes of its habits and habitat is a discovery.

Conversion of Fathoms and Metres

1 fathom	= 1·8288 metres		1 metre	= 0·5468 fathom	
2 fathoms	= 3·6576	,,	2 metres	= 1·0936 fathoms	
3 ,,	= 5·4864	,,	3 ,,	= 1·6404	,,
4 ,,	= 7·3152	,,	4 ,,	= 2·1872	,,
5 ,,	= 9·1440	,,	5 ,,	= 2·7341	,,
6 ,,	= 10·9728	,,	6 ,,	= 3·2809	,,
7 ,,	= 12·8016	,,	7 ,,	= 3·8277	,,
8 ,,	= 14·6304	,,	8 ,,	= 4·3745	,,
9 ,,	= 16·4592	,,	9 ,,	= 4·9213	,,

A little use of the decimal point will enable any conversion of fathoms into metres, or the converse. Thus, suppose that it is desired to find how many metres are equal to 1,537 fathoms:

1,000 fathoms	=	1,828·80 metres	
500 ,,	=	914·40	,,
30 ,,	=	54·86	,,
7 ,,	=	12·80	,,
1,537 fathoms	=	2,810·86 metres	

Meridians used in some Foreign Charts in Terms of Longitude from Greenwich

Amsterdam	4° 53′ 4″ E.	Lisbon .	9° 7′ 56″ W.
Cadiz .	6° 12′ 24″ W.	Naples .	14° 14′ 43″ E.
Oslo	10° 43′ 26″ E.	Paris .	2° 20′ 15″ E.
Ferro .	18° 10′ 0″ W.	Leningrad	30° 19′ 40″ E.

Thermometric Conversion

The following tables can be used for air temperatures and ordinary work; but, as having only one place of decimals, they are not accurate enough to satisfy the modern hydrographer.

Conversion of Centigrade into Fahrenheit

° C. = ° F.	° C. = ° F.	° C. = ° F.	° C. = ° F.	° C. = ° F.
55 = 131·0	37 = 98·6	19 = 66·2	1 = 33·8	13 = 8·6
54 = 129·2	36 = 96·8	18 = 64·4		14 = 6·8
53 = 127·4	35 = 95·0	17 = 62·6	Plus	15 = 5·0
52 = 125·6	34 = 93·2	16 = 60·8	0 = 32·0	16 = 3·2
51 = 123·8	33 = 91·4	15 = 59·0		17 = 1·4
50 = 122·0	32 = 89·6	14 = 57·2	Minus	
49 = 120·2	31 = 87·8	13 = 55·4	1 = 30·2	
48 = 118·4	30 = 86·0	12 = 53·6	2 = 28·4	
47 = 116·6	29 = 84·2	11 = 51·8	3 = 26·6	Decimals
46 = 114·8	28 = 82·4	10 = 50·0	4 = 24·8	0·1 = 0·18
45 = 113·0	27 = 80·6	9 = 48·2	5 = 23·0	0·2 = 0·36
44 = 111·2	26 = 78·8	8 = 46·4	6 = 21·2	0·3 = 0·54
43 = 109·4	25 = 77·0	7 = 44·6	7 = 19·4	0·4 = 0·72
42 = 107·6	24 = 75·2	6 = 42·8	8 = 17·6	0·5 = 0·90
41 = 105·8	23 = 73·4	5 = 41·0	9 = 15·8	0·6 = 1·08
40 = 104·0	22 = 71·6	4 = 39·2	10 = 14·0	0·7 = 1·26
39 = 102·2	21 = 69·8	3 = 37·4	11 = 12·2	0·8 = 1·44
38 = 100·4	20 = 68·0	2 = 35·6	12 = 10·4	0·9 = 1·62

Example—to convert 17·6° C. into Fahrenheit:

17·0° C. = 62·6° F.
0·6 C. = 1·08 F.
17·6° C. = 63·68 F.

General formulae:

$$°\ F. = \frac{9}{5}\ C. + 32$$

$$°\ C. = \frac{5\ (°\ F. - 32)}{9}.$$

Conversion of Fahrenheit into Centigrade

° F. = ° C.	° F. = ° C.	° F. = ° C.	° F. = ° C.	° F. = ° C.	° F. = ° C.
130 = 54·4	108 = 42·2	86 = 30·0	64 = 17·7	42 = 5·5	22 = 5·5
129 = 53·8	107 = 41·6	85 = 29·4	63 = 17·2	41 = 5·0	21 = 6·1
128 = 53·3	106 = 41·1	84 = 28·8	62 = 16·6	40 = 4·4	20 = 6·6
127 = 52·7	105 = 40·5	83 = 28·3	61 = 16·1	39 = 3·8	19 = 7·2
126 = 52·2	104 = 40·0	82 = 27·7	60 = 15·5	38 = 3·3	18 = 7·7
125 = 51·6	103 = 39·4	81 = 27·2	59 = 15·0	37 = 2·7	17 = 8·3
124 = 51·1	102 = 38·8	80 = 26·6	58 = 14·4	36 = 2·2	16 = 8·8
123 = 50·5	101 = 38·3	79 = 26·1	57 = 13·8	35 = 1·6	15 = 9·4
122 = 50·0	100 = 37·7	78 = 25·5	56 = 13·3	34 = 1·1	14 = 10·0
121 = 49·4	99 = 37·2	77 = 25·0	55 = 12·7	33 = 0·5	13 = 10·5
120 = 48·8	98 = 36·6	76 = 24·4	54 = 12·2	Plus	12 = 11·1
119 = 48·3	97 = 36·1	75 = 23·8	53 = 11·6	32 = 0·0	11 = 11·6
118 = 47·7	96 = 35·5	74 = 23·3	52 = 11·1	Minus	10 = 12·2
117 = 47·2	95 = 35·0	73 = 22·7	51 = 10·5	31 = 0·5	9 = 12·7
116 = 46·6	94 = 34·4	72 = 22·2	50 = 10·0	30 = 1·1	8 = 13·3
115 = 46·1	93 = 33·8	71 = 21·6	49 = 9·4	29 = 1·6	7 = 13·8
114 = 45·5	92 = 33·3	70 = 21·1	48 = 8·8	28 = 2·2	6 = 14·4
113 = 45·0	91 = 32·7	69 = 20·5	47 = 8·3	27 = 2·7	5 = 15·0
112 = 44·4	90 = 32·2	68 = 20·0	46 = 7·7	26 = 3·3	4 = 15·5
111 = 43·8	89 = 31·6	67 = 19·4	45 = 7·2	25 = 3·8	3 = 16·1
110 = 43·3	88 = 31·1	66 = 18·8	44 = 6·6	24 = 4·4	2 = 16·6
109 = 42·7	87 = 30·5	65 = 18·3	43 = 6·1	23 = 5·0	1 = 17·2
					0 = 17·7

Nautical and Geographical Miles

Nautical mile = 6,080 ft. Geographical mile = 6,086 ft.

The nautical mile is one minute of latitude. Since the earth is not truly spherical, the length of a minute of latitude increases from 6,046 ft. at the equator to 6,108 ft. at the poles. For navigational purposes and chart work an average value (6,080 ft.) is always used. On plans (charts of small area, such as harbours), the 'minute of latitude in' the place—that is to say, its true value in the place—is used instead of the nautical mile.

The geographical mile is one minute of longitude on the equator.

Abbreviations for Bottom Deposits used in Admiralty Charts (Admiralty Chart, X, 11)

b.	blue.	peb.	pebbles.
blk.	black.	r.	rock.
br.	brown.	rot.	rotten.
brk.	broken.	s.	sand.
c.	coarse.	sft.	soft.
cl.	clay.	sh.	shell.
crl.	coral.	spk.	speckled.
d.	dark.	st.	stones.
f.	fine.	stf.	stiff.
g.	gravel.	w.	white.
gn.	green.	wd.	weed.
grd.	ground.	y.	yellow.
gy.	grey.	for.	Foraminifera.
h.	hard.	gl.	Globigerina.
m.	mud.	pt.	Pteropod.
oys.	oysters.	rad.	Radiolaria
oz.	ooze.		

WIND, WEATHER, AND FOG SCALES[1]

WIND

No.	Description	Miles per Hour	No.	Description	Miles per Hour
0	Calm . .	Under 1	7	Strong wind	32 to 38
1	Light breeze .	1 to 3	8	Gale force	39 „ 46
2	„ „ .	4 „ 7	9	„ „	47 „ 54
3	„ „ .	8 „ 12	10	Storm force	55 „ 63
4	Moderate breeze	13 „ 18	11	„ „	64 „ 75
5	„ „	19 „ 24	12	Hurricane	—
6	Strong wind .	25 „ 31			

WEATHER

b. blue sky.
c. clouds, detached.
d. drizzling rain.
e. wet without rain.
f. fog.
g. gloomy.
h. hail.
l. lightning.
m. misty.
o. overcast.
p. passing showers.
q. squally.
r. rain.
s. snow.
t. thunder.
u. ugly appearance of weather.
v. objects unusually visible.
w. dew.
z. haze.

Intensity can be indicated by underlining. Duration of rain, hail, snow, and sleet should always be recorded, and can be indicated by a numeral preceding the letter; thus 5r = five hours of rain.

FOG

No.	Description
0	No fog or mist, horizon clear.
1	Light fog or mist, horizon invisible; objects visible at working distances.
2, 3	Moderate fog; lights, passing vessels, and landmarks generally indistinct under a mile. Fog signals sounded.
4, 5	Thick fog; ships' lights and vessels invisible at quarter-mile or less.

[1] Abbreviated from those issued by the Meteorological Office; revised form of Beaufort's scales.

MARINE STATIONS

It is hoped that this section may prove useful to travellers in need of local information. Even those State or Official stations marked †, which are not open to researchers from outside, may be relied upon in most cases for advice and assistance.

The list has been revised by means of the 'Index Generalis' for 1925–6; the editor is also indebted to Dr. Yô Okada for information about Japanese stations, and to Dr. C. Jucci for Italian stations.

Country	Name of Station and its Administration	Director
Belgium:		
Ostende	Laboratoire Maritime	G. Gilson.
Denmark:		
Copenhagen	Carlsberg Laboratorium	Johs. Schmidt.
"	Danske Biologiske Station, and Kommissionen for Havundersøgelser	A. C. Johansen.
" †	International Council for the Exploration of the Sea. Headquarters at Strandvej 34, Hellerup, Copenhagen	
Egypt:		
Alexandria †	Fisheries Research Office, Coastguards and Fisheries Service	R. S. Wimpenny.
"	Institut Hydrobiologique Sultanien	D. Pachundaki.
Finland:		
Helsingfors	Oceanographical Institute (Merentutkimuslaitos)	R. Witting.
France:		
Ambleteuse, Pas-de-Calais	Laboratoire Charles Maurice	H. Boulangé.
Arcachon, Gironde	Station Biologique de la Société Scientifique d'Arcachon	R. Sigalas.
Banyuls-sur-Mer, Pyrén.-Orient.	Laboratoire Arago de la Faculté des Sciences de Paris	O. Duboscq.
Boulogne-sur-Mer, Pas-de-Calais †	Laboratoire de l'Office Scientifique et Technique des Pêches Maritimes	F. le Gall.

Cette, Hérault . .	Station Zoologique de l'Université de Montpellier	E. Bataillon.
Concarneau, Finistère .	Laboratoire du Collège de France	F. Henneguy.
Endoume, Bouches-du-Rhône	Laboratoire Marion de Marseille	M. Kollman.
Guethary, Bas.-Pyrén. .	Annexe to Arcachon Station	C. Sauvageau
La Rochelle, Charente-Inférieure	Laboratoire de l'Office Scientifique et Technique des Pêches Maritimes	G. Belloc.
Le Croisic, Seine-Inférieure	Laboratoire de *Biologie Marine*	A. Labbé.
Le Havre, Seine-Inférieure	Laboratoire de l'Institut Océanographique du Havre	A. Loir.
Luc-sur-Mer, Calvados	Laboratoire Maritime de l'Université de Caen	L. Mercier.
Paris †	Institut Océanographique, 195 Rue Saint-Jacques	L. Joubin.
"	Office Scientifique et Technique des Pêches Maritimes, 3 Avenue Octave Gréard	E. le Danois.
Roscoff, Finistère . .	Laboratoire Lacaze-Duthiers	C. Pérez.
Saint-Servan, Ille-et-Vilaine	Laboratoire Maritime du Musée National d'Histoire Naturelle	L. Mangin.
Tamaris-sur-Mer, Var .	Laboratoire de l'Université de Lyon	
Villefranche-sur-Mer, Alpes Maritimes	Station Zoologique Russe	M. Davidoff.
Wimereux, Pas-de-Calais	Station Zoologique Alfred Giard	M. Caullery.
RENCH COLONIES:		
Algeria		
Algiers . . .	Laboratoire de la jetée nord d'Alger	L. Boutan.
Castiglione . . .	Station expérimentale d'Aquiculture et de Pêche	M. Gavard.
Annam		
Caoda	Laboratoire d'Océanographie	A. Krempf.
Cochin China		
Saigon . . .	Institut Scientifique de Saigon	A. Krempf.
Martinique		
Fort-de-France . .	Institut Océanographique	M. Conseil.

MARINE STATIONS—*Continued*.

Country	Name of Station and its Administration	Director
FRENCH PROTECTORATES:		
Morocco		
Rabat	Institut Scientifique Chérifien	R. Liouville.
Tunis		
Salammbô, near Carthage	Station Océanographique	H. Heldt.
GERMANY:		
Hamburg †	Fischereibiologische Abteilung des Zoologischen Staatsinstituts und Zoologischen Museums, Kirchenallee 47, Hamburg 5	E. Ehrenbaum.
Helgoland	Staatliche Biologische Anstalt	W. Mielck.
Kiel	Staats-Institut des preussischen Landwirtschafts-Ministeriums	K. Brandt.
GREAT BRITAIN:		
England		
Cullercoats	Marine Laboratory of Armstrong College, Newcastle-upon-Tyne	A. Meek.
Lowestoft †	Laboratory of Ministry of Agriculture and Fisheries	E. S. Russell.
Plymouth	Marine Biological Association of United Kingdom	E. J. Allen.
Port Erin, Isle of Man	Port Erin Marine Biological Station (Liverpool M.B. Committee)	J. Johnstone.
Scotland		
Aberdeen †	Laboratory of Fishery Board for Scotland, Wood Street, Torry, Aberdeen	A. Bowman.
Millport	Scottish Marine Biological Association	R. Elmhirst.
Wales		
Conway †	Laboratory of Ministry of Agriculture and Fisheries for Mollusc Research	R. W. Dodgson.

BRITISH COLONIES:		
Bermuda	Marine Biological Station	E. L. Mark.
Canada		
Halifax, N.S. †	Fisheries Experimental Station (Atlantic)	W. A. Clemens.
Nanaimo, B.C.	Pacific Biological Station	"
Prince Rupert, B.C. †	Fisheries Experimental Station (Pacific)	A. G. Huntsman.
St. Andrews, N.B.	Atlantic Biological Station	"
India		
Colombo, Ceylon †	Fisheries Department	J. Pearson.
Madras †	Fisheries Department	B. Sundara Raj.
New Zealand		
Port Chalmers †	Marine Biological Station	A. E. Hefford.
Malay States		
Malay †	Fisheries Department	F. Green.
GREECE:		
Vieux Phalère	Station Biologique de la Commission Thalassographique Hellénique	N. Sperantsas.
HOLLAND:		
Helder	Zoologisch Station der Nederlandsche Dierkundige Vereeiniging	H. C. Redeke.
HUNGARY:		
Budapest	Oceanographical Institute of Hungary	G. Leidenfrost.
IRELAND:		
Dublin †	Office of Irish Fisheries Department, Kildare Street	G. P. Farran.

MARINE STATIONS—*Continued.*

Country	Name of Station and its Administration	Director
ITALY:		
Genoa	Instituto di Zoologia della R. Università di Genova	R. Issel.
Messina, Sicily	Instituto Centrale di Biologia Marina	L. Sanzo.
Naples	Stazione Zoologica	R. Dohrn.
Rovigno, Istria	Instituto di Biologia Marina per l'Adriatico del R. Comitato Talassografico Italiano	M. Sella.
San Bartolommeo di Cagliari, Sardinia	R. Stazione Biologica dell' Università di Cagliari	E. Giglio-Tos.
Taranto †	Laboratorio di Biologia Marina (for Oyster Culture and Fisheries Research)	A. Cerruti.
JAPAN:		
Hokkaidô		
Oshoro †	Hokkaido Imperial University Fisheries College	K. Fujita.
Takashma †	Government Research Station	I. Moriwaki.
Séto †	Government Research Station	K. Fuji.
Hondo		
Asamushi	Tôhoku Imperial University Science Department Laboratory	S. Hatai.
Hojô, Takanoshima †	Government Research Station of College of Fisheries	K. Okamura.
Misaki	Tokyo Imperial University Laboratory	N. Yatsu.
Seto, Tanabé	Kyoto Imperial University Laboratory	T. Komai.
Saganoseki, Ôita Prefecture	Kyoto Imperial University Laboratory	
Toyota-Gun, Hiroshima Prefecture †	Government Research Station	E. Kajiyama.
Korea		
Fusan †	Government Research Station	Y. Wakiva.

LATVIA:		
Riga	Hydrobiologische Station der lettländischen Universität in Riga	E. Strand.
MONACO:		
Monaco	Laboratoire du Musée Océanographique (Fondation Albert Ier)	J. Richard.
NORWAY:		
Drobak	Biologiske Station Universitets Oslo	H. Broch.
Flødevigen †	Fish Hatchery of the Fisheries Society of Arendal	G. M. Dannevig.
Herdla, Bergen	Biologiske Station Bergens Museum	A. Brinkmann.
Trondjhem	Marine Biological Station	O. Nordgaard.
PORTUGAL:		
Dafundo, Lisbon	Aquário Vasco da Gama, Estação de Biologia Maritima	A. Ramalho.
Porto	Estação de Zoologia Maritima, Universidade de Porto	
RUSSIA (U.S.S.R.):		
Moscow †	Institut Scientifique Maritime	
Vladivostock	Pacific Ocean Scientific Fishery Research Station, Bassargin, Bay of Ussurüskü, near Vladivostock	
SPAIN:		
Madrid †	Instituto Español de Oceanografía, Calle de Alcalá, 31	O. de Buen.
Malaga	Estacion de Biología Marina, Avenue de Flores García	A. de Miranda.
Palma de Mallorca	Laboratorio Biologico-marino de Baleares	F. Navarro Martín.
Santander	Estación de Biología Marítima, Calle de Castelar	L. Alaejos.
SWEDEN:		
Fiskebackskil	Kristineberg Zoologiska Station (Royal Swedish Academy of Science)	
Goteborg	Svenska Hydrografisk-Biologiska Kommissionen	O. Pettersson.

MARINE STATIONS—*Continued.*

Country	Name of Station and its Administration	Director
UNITED STATES OF AMERICA:		
Beaufort, N.C. †	Laboratory of Bureau of Fisheries	S. F. Hildebrand.
Bermuda	(*See* British Colonies)	
Cold Spring Harbour, Long Island	Biological Laboratory of the Long Island Biological Association	R. G. Harris.
Fairport, Iowa †	Laboratory of Bureau of Fisheries	
Friday Harbour, Washington	Puget Sound Biological Station of the University of Washington	T. C. Frye.
Honolulu, Hawaii	Marine Biological Laboratory of University of Hawaii	C. H. Edmondson.
Key West, Florida	Laboratory of Bureau of Fisheries	
Laguna Beach, California	Marine Laboratory of Pomona College	W. A. Hilton.
La Jolla, California	Scripps Institute of Oceanography	T. Wayland Vaughan.
Los Angeles, California	Marine Biological Station of University of Southern California	A. B. Ulrey.
Mount Desert, Bar Harbour, Maine	Biological Survey of Mount Desert Region	W. Procter.
Pacific Grove, Monterey, California	Hopkins Marine Station of Stanford University	W. K. Fisher.
San Francisco, California	California Academy of Sciences	B. W. Evermann.
Terminal Island, California †	California State Fisheries Laboratory	W. L. Scofield.
Tortugas, Florida	Marine Laboratory of Carnegie Institution of Washington	W. H. Longley.
Washington †	Bureau of Fisheries, Department of Commerce	
Woods Hole, Mass. †	Laboratory of Bureau of Fisheries	
Woods Hole, Mass.	Marine Biological Laboratory	M. H. Jacobs.

CLASSIFICATION TABLES

These classifications are intended simply to enable untrained observers readily to pigeon-hole the animals and plants mentioned in the book. Their aim is practical: accordingly they are not complete schemes of the animal and vegetable kingdoms, nor do they in all details conform to the latest classifications used by scientific authorities. Only those features of the animals are mentioned which can be understood without a knowledge of anatomy.

ANIMALS

A. **Protozoa.** Minute: the body not composed of cells of different kinds.

I. **Sarcodina (Gymnomyxa).** The body bears temporary lobes or rootlets of protoplasm 'pseudopodia').

1. **Amoeboidea (Amoebina).** Creeping forms, without shell or skeleton. *Amoeba.*
2. **Foraminifera.** Creepers, and a few floaters, with shell but no skeleton. *Astrorhiza, Biloculina, Candeina, Globigerina, Hastigerina, Lagena, Lituola, Miliola, Nummulina, Orbulina, Polytrema, Pulvulina, Rotalia, Sphaeroidina, Textularia.*
3. **Radiolaria.** Floaters, with no shell, but usually a lattice skeleton. *Acanthometra, Challengerion, Coelodendrum, Collozoum, Conchidium, Euphysetta, Eucyrtidium, Helicosphaera, Stylospira, Tuscarora.*

II. **Mastigophora (Flagellata).** The body bears a few long lashes of protoplasm ('flagella').

1. **Chrysomonadina.** Yellow or brown: no gullet: not girdled by a flagellum.
   Coccolithophoridae, *Dinobryon,* Silicoflagellata.
2. **Euglenoidina.** Green: a gullet: not girdled by a flagellum.
   Euglena.
3. **Dinoflagellata.** Yellow, green, or colourless: no gullet: girdled by a flagellum, in a groove of the body.
   Ceratium, Noctiluca, Peridinium, Pyrocystis.

III. **Ciliata.** The body bears many short lashes of protoplasm ('cilia').
Tintinnus.

B. **Parazoa (Porifera).** Small or medium-sized: body composed of many cells of several kinds: entrance to body by numerous pores.
Clione, Euspongia, Euplectella, Holtenia, Sycon [Sponges].

C. **Metazoa.** Small to large: body composed of many cells of many kinds: entrance by a mouth.

I. **Coelenterata.** Radial (star-like) symmetry: no arms: tentacles: most have stinging-cells [Polyps, Jelly-fishes, &c.].

C. Metazoa.—I. Coelenterata.—(*cont.*).

1. **Hydrozoa** (**Hydromedusae**). Small polyps: not partitioned inside: often without jelly-fish offspring.

   i. **Hydroida.** Polyps, solitary or 'colonial' (i.e. connected with one another by living tissue to form a plant-like stock), without lime skeleton.

   Bougainvillea, Cladocarpus, Coryomorpha (*Euphysa*), *Obelia, Phialidium.*

   ii. **Hydrocorallinae.** Colonial polyps with heavy skeleton ('coral') of carbonate of lime.

   Millepora, Stylaster.

   iii. **Siphonophora.** Floating colonies, without skeleton.

   Diphyes, Physalia, Porpita, Velella.

2. **Scyphozoa** (**Scyphomedusae, Acalephae**). Large jelly-fish, with small polyps, if any.

   Aurelia, Pelagia, Rhizostomum.

3. **Anthozoa** (**Actinozoa**). Large polyps, usually colonial, with vertical partitions inside, and no jelly-fish offspring.

   i. **Alcyonaria.** Eight feathered tentacles.

   Alcyonium, Corallium, Gorgonia, Heliopora, Lobophytum, Pennatula, Sarcophytum, Tubipora, Xenia.

   ii **Zoantharia.** Various numbers of tentacles, which are not feathered.

   a. **Actiniaria.** Without skeleton [Sea Anemones].

   Actinia, Arachnactis, Zoanthus.

   b. **Antipatharia.** With horny skeleton [Black Corals].

   Antipathes.

   c. **Madreporaria.** With skeleton of carbonate of lime [Stone Corals].

   Acropora, Caryophyllia, Dendrophyllia, Euphyllia, Heteropsammia, Leptopenus, Madrepora, Montipora, Mussa, Pavona, Pocillopora, Porites, Stylophora, Turbinaria.

4. **Ctenophora.** Transparent: not resembling polyps or medusae: paddles of fused cilia as swimming organs: no stinging cells.

   Beroe, Bolina, Cestus, Pleurobrachia.

II. **Platyhelminthes.** Bilateral symmetry: body usually flat: no arms [Flatworms].

1. **Turbellaria.** Non-parasitic: ciliated.

   Convoluta, Leptoplana, Pseudoceros.

2. **Trematoda.** Parasitic: not ciliated: with mouth and gut [Flukes].

   Gasterostomum, Octobothrium.

3. **Cestoda.** Parasitic: not ciliated: without mouth and gut [Tapeworms].

   Phyllobothrium, Tetrarhynchus.

III. **Nemertina** (**Nemertea**). Worm-like: ciliated: with proboscis.

Lineus.

IV. **Nematoda.** Worm-like: covered not with cilia but with a stout cuticle: without proboscis.

Enoplus, Eustrongylus.

V. **Chaetognatha.** Straight, transparent worms: with horizontal fins: sickle-shaped teeth.
Sagitta, Spadella.

VI. **Rotifera.** Small, transparent, bilateral animals: a wreath of cilia on the head: a cuticle on the rest of the body: an active gizzard.
Brachionus, Synchaeta.

VII. **Sipunculoidea.** Unsegmented burrowing worms, with tentacles round the mouth.
Sipunculus.

VIII. **Echiuroidea.** Unsegmented worms, without tentacles but with a proboscis, which live in burrows or crevices [Spoonworms].
Echiurus.

IX. **Annelida.** Segmented worms.

1. **Archiannelida.** No limbs, bristles, or suckers.
Polygordius.
2. **Polychaeta.** Paired limbs ('parapodia') on some or all segments: bristles: no sucker.
Amphinome, Aphrodite, Arenicola, Autolytus, Bispira, Chaetopterus, Drilonereis, Eunice, Hermione, Hyalinoccia, Myzostoma, Nerine, Palola, Sabella, Serpula, Tomopteris.
3. **Oligochaeta.** Bristles: no limbs or suckers [Earthworms, &c.].
Clitellio.
4. **Hirudinea.** No limbs or bristles: two suckers [Leeches].
Pontobdella.

X. **Arthropoda.** Segmented: with stout cuticle: and jointed limbs, some of which act as jaws.

1. **Crustacea.** Two pairs of antennae: breathing by gills.
   - i. **Branchiopoda Cladocera.** Small: with shell, which does not enclose the head [Water-fleas].
   Evadne.
   - ii. **Ostracoda.** Small: with bivalve shell, which encloses the head.
   Conchoecia.
   - iii. **Copepoda.** Small: without shell: females carry egg-packets: many parasitic.
   Calanus, Caligus, Sapphirina, Temora.
   - iv. **Cirripedia.** Fixed by a stalk or base: enclosed in a mantle or shell, usually of several pieces [Barnacles].
   Balanus, Coronula, Conchoderma, Lepas, Scalpellum.
   - v. **Malacostraca.** The larger crustaceans.
     - a. **Schizopoda.** A shell ('carapace'): stalked eyes: no claws.
       - (1) **Euphausiacea.** Without brood-pouch.
       Boreophausia, Euphausia, Nyctiphanes.
       - (2) **Mysidacea.** With a brood pouch under the body.
       Gnathophausia, Mysis.
     - b. **Cumacea.** A carapace: eyes unstalked: no claws.
     Diastylis.

C. Metazoa.—X. Arthropoda.—1. Crustacea—(*cont.*).

c. Isopoda. No carapace: flat from above down—woodlouse-like. [Slaters]. *Cirolana, Rocinela, Serolis.*

d. Amphipoda. No carapace: flat from side to side—sandhopper-like. *Caprella, Epimeria, Euthemisto, Phronima.*

e. Stomatopoda. A carapace: stalked eyes: clasp-knife claws. *Squilla.*

f. Decapoda. A carapace: stalked eyes: usually pincer claws.

(1) Macrura. A strong, straight hind-body ('tail' or abdomen) [Prawns, Lobsters, &c.].
Acanthephyra, Callianassa, Eryx, Nephrops, Palinurus, Penaeus, Sergestes, Willemoesia.

(2) Anomura. Hind-body reduced or twisted [Hermit Crabs, &c.].
Albunea, Hippa, Remipes.
Galathea, Munida.
Catapagurus, Diogenes, Pagurus.

(3) Brachyura. Hind-body turned under forepart [Crabs].
Atelecyclus, Bathynectes, Corystes, Cryptochirus, Ebalia, Gelasimus, Hapalocarcinus, Homolodromia, Melia, Ocypode.

2. Insecta. One pair of antennae: breathing by air-tubes: three pairs of legs.
Halobates.

3. Arachnida. No antennae: breathing by lungs or gills: four pairs of legs [Spiders, King-crabs, &c.].
Desis, Limulus.

4. Pycnogonida. Neither antennae, gills, lungs, nor air-tubes: four pairs of legs: very small body.
Pycnogonum.

XI. Mollusca. Unsegmented: soft-bodied: with a shell, sometimes internal or lost: and a muscular foot [Shellfish].

1. Lamellibranchiata (Pelecypoda). Shell bivalve: no tongue or eyes [Oysters, Mussels, Clams, &c.].
Lithodomus, Mactra, Mya, Ostrea, Spisula, Tridacna.

2. Amphineura. Shell, if any, a row of pieces on the back: a tongue: no eyes.
Chiton, Cryptoplax.

3. Gastropoda. Shell, if any, in one piece: a tongue: eyes: body twisted (snail-like) [Whelks, Snails, &c.].
Pteropoda: *Cavolinia, Clio, Creseis, Hyalaea, Limacina, Styliota.*
Heteropoda: *Atlanta, Carinaria, Oxygurus.*
Nudibranchiata: *Chromodoris, Doris, Eolis.*
Other forms: *Ianthina, Vermetus.*

4. Cephalopoda. Shell, if any, in one piece, usually internal or absent: a tongue: eyes: the foot transformed into a funnel: arms surround the mouth [Cuttle-fishes].
Argonauta, Benthoteuthis, Eledone, Loligo, Nautilus, Octopus, Sepia, Sepiola, Spirula.

XII. **Brachiopoda.** Bivalve shell: coiled arms: anatomy unlike that of bivalve molluscs [Lamp shells].
Terebratula.

XIII. **Polyzoa.** Small: bilaterally symmetrical: with a crown of tentacles: fixed, and usually united into colonies.
Bowerbankia, Cellularia.

XIV. **Echinodermata.** Radial (star-like) symmetry: arms present: skin contains ossicles of carbonate of lime.

1. **Asteroidea.** Star-shaped, with wide arms [Starfishes].
Archaster.
2. **Ophiuroidea.** Star-shaped, with slender arms [Brittle Stars].
Amphiura, Ophiura.
3. **Echinoidea.** Globe or heart-shaped, without arms [Sea Urchins].
Brissopsis, Echinus, Echinocardium, Salenia.
4. **Holothuroidea.** Cucumber-shaped [Sea Cucumbers or Trepangs].
Holothuria, Synapta.
5. **Crinoidea.** Star-shaped, with branched arms: fastened permanently or temporarily with mouth upwards.
Antedon, Rhizocrinus.

XV. **Chordata.** Though very unlike one another, these have in common the following peculiarities: the centre of the nervous system lies on the back: and the embryo (and often the adult) possesses gill slits through the sides of its throat, and an elastic rod (the 'notochord') along the back under the central nervous system.

1. **Hemichordata (Enteropneusta).** Worm-like: without tail.
Balanoglossus, Ptychodera, Spengelia.
2. **Urochorda (Tunicata).** The young tadpole-like, with a tail: the adult usually a degenerate sack-like creature.
Appendicularia, Ascidia, Doliolum, Pyrosoma, Salpa.
3. **Cephalochorda.** A tail present: adult not degenerate: no bone, cartilage, heart, or brain.
Amphioxus.
4. **Vertebrata.** A tail: a skeleton of bone or cartilage: and a highly developed heart and brain.
   - i. **Pisces.** Gill breathers: limbs are fins: cold blooded [Fishes].
     - a. **Elasmobranchii.** Skeleton of cartilage only: no air-bladder [Sharks, Rays, &c.].
     Chimaera, Raja, Scyllium.
     - b. **Teleostei.** Skeleton contains bone: an air-bladder.
     Argyropelecus, Gadus, Gobius, Lepadogaster, Macrurus, Osmerus, Regalecus, Scopelus, Scorpaena, Solea, Stomatias.
   - ii. **Reptilia.** Lung breathers: limbs have fingers and toes: cold blooded.
   Distira, Hydrus.
   - iii. **Mammalia.** Lung breathers: limbs have finger and toe bones: warm blooded: the young born resembling the adults and fed with milk.
     - a. **Cetacea.** No hind limbs: tail has flukes: nostrils on top of head: young born at sea [Whales and Dolphins].

C. Metazoa.—XV. Chordata.—4. Vertebrata—(*cont.*).

(1) Odontoceti. Toothed whales.

Berardius, Delphinus, Globicephalus, Hyperoodon, Inia, Kogia, Lagenorhynchus, Mesoplodon, Orca, Physeter, Platanista.

(2) Mystacoceti. Whalebone whales.

Balaena, Balaenaptera, Megaptera, Pontoporeia, Rachianectes, Sotalia, Ziphius.

b. Carnivora Pinnipedia. Hind limbs present: tail small, without flukes: nostrils on snout: young born on land.

Otariidae. External ears present: hind limbs can turn forwards [Eared Seals].

Eumetopias, Otaria, Zalophus.

Trichechidae. No external ears: hind limbs can turn forwards: upper canine teeth are tusks [Walrus].

Trichechus.

Phocidae. No external ears: hind limbs turned back and united with tail [True Seals].

Cystophora, Erignathus, Halichoerus, Histriophoca, Lobodon, Macrorhinus, Monachus, Ommatophoca, Peptonyx, Phoca, Stenorhynchus.

PLANTS

A. Thallophyta.

I. Myxophyceae (Cyanophyceae).

1. Chroococcaceae.
2. Nostocaceae.

Calothrix, Lyngbya, Rivularia, Scytonema, Trichodesmium.

II. Chrysomonadinae.

1. Coccolithophoridae.

Coccosphera, Rhabdosphera.

III. Dinoflagellata.

1. Peridiniae.

Ceratium, Peridinium, Ornithocercus.

2. Pyrocystidae.

Pyrocystis.

IV. Acontae.

1. Diatomaceae.

Bacteriastrum, Chaetoceras, Coscinodiscus, Pinnularia, Planktoniella, Sceletonema.

V. Chlorophyceae.

1. Halosphaeraceae.

Halosphaera.

2. Ulvaceae.

Enteromorpha, Monostroma, Ulva.

3. Cladophoraceae.

Chaetomorpha, Cladospora, Urospora.

4. Dasycladaceae.

Acetabularia, Bornetella, Cymopolia, Neomeris.

5. Codiaceae.
   Halimeda, Penicillus, Udothea.
6. Caulerpaceae.
   Caulerpa.

VI. Phaeophyceae.

1. Ectocarpaceae.
   Ectocarpus.
2. Encoeliaceae.
   Asperococcus.
3. Desmarestiaceae.
   Desmarestia.
4. Ralfsiae.
   Ralfsia.
5. Laminariaceae.
   Ecklonia, Egregia, Eisenia, Laminaria, Lessonia, Macroc stis, Nereocystis, Saccorhiza.
6. Cutleriaceae.
   Cutleria.
7. Fucaceae.
   Ascophyllum, Cystophyllum, Cystoseira, Durvillaea, Fucus, Halidrys, Himanthalia, Hormoseira, Notheia, Pelvetia, Sargassum, Scytothalia, Turbinaria.
8. Dictyotaceae.
   Dictyota, Halyseris, Lobospira, Padina, Taonia.

VII. Rhodophyceae.

1. Helminthocladiaceae.
   Nemalion.
2. Gigartinaceae.
   Gigartina.
3. Rhodymeniaceae.
   Rhodymenia.
4. Delesseriaceae.
   Claudea, Delesseria, Martensia, Vanvoorstia.
5. Rhodomelaceae.
   Laurencia, Polysiphonia.
6. Ceramiaceae.
   Ceramium, Ptilota.
7. Grateloupiaceae.
   Halymenia.
8. Corallinaceae.
   Amphiroa, Arthrocardia, Corallina, Lithophyllum, Lithothamnion, Melobesia.

B. Phanerogamia.

Potamogetonaceae.
   Cymodocea.

Hydrocharidaceae.
   Halophila.

LITERATURE

ONLY the merest outline of a guide to the literature of the subject can be given here. A general view of terrestrial phenomena, 'popularly' written but scientifically sound, is furnished by Dr. H. R. Mill's 'Realm of Nature'. Further, Wyville Thomson's 'Depths of the Sea', Alcock's 'Naturalist in Indian Seas', Moseley's 'Notes by a Naturalist on H.M.S. *Challenger*', and 'Three Cruises of the *Blake*', by Agassiz, supply accounts of typical expeditions which are excellent and valuable reading. Of more recent books must be mentioned 'The Oceans' by Sir John Murray, 'Founders of Oceanography' by Sir William Herdman, 'An Introduction to Oceanography' and 'A Study of the Oceans' by Professor James Johnstone, 'The Biology of the Sea Shore' by Flattely and Walton, and 'The Depths of the Ocean' by Sir John Murray and Professor Johan Hjort, a book of extreme interest and value to the serious student of the subject, while 'The Seas' by Russell and Yonge covers in a popular style the many branches of oceanography.

From such we have to plunge almost at once into the more technical monographs. As a rule the most valuable are those of the large expeditions, such as the 'National' or Plankton Expedition (North Atlantic Ocean), the 'Valdivia' (Atlantic and Indian Oceans), the Siboga (East Indies) and the Danish 'Ingolf' Expedition (North Atlantic), while many of the *Challenger* Reports, although tending to become out of date for systematic work, are still absolutely indispensable. The majority of these are zoological and botanical reports, but there are also volumes dealing with chemistry, physics, meteorology, and equipment. The monographs of the Naples Station are the best guide in some groups. Once the observer has selected his subject or his group, he will make a selection from these sources.

Beyond them lies the nebulous myriad of papers scattered in technical journals. For zoologists the best path is the card-catalogue prepared by the *Challenger* Society, which can be seen in London at the Natural History Museum; by this means it is possible to find all that has been published on the marine fauna of a region, or even of a lonely island. But many Reports of Expeditions contain very full lists of special papers.

General zoological and botanical text-books of all grades are only

too numerous. For the purposes of the reader whom we have in mind, the volumes of the 'Cambridge Natural History' are to be recommended, and on the botanical side Murray's 'Introduction to the Study of Seaweeds' will be found helpful. Anatomical and systematic text-books are beyond the scope of this work, but mention should be made of such faunistic books as Mortensen's 'British Echinoderms', Stephenson's 'British Sea Anemones', and the German volumes of 'Die Tierwelt der Nord-und Ostsee', which are invaluable forthe identification of specimens.

I. THE AIR

1. Barometer Manual
2. Seaman's Handbook of Meteorology
3. Marine Observer's Handbook
4. Observer's Handbook
5. Weather Map and Glossary
6. Marine Observer (published monthly)

Published by the Meteorological Office

7. 'Meteorology': Lempfert.
8. 'Forecasting Weather': Sir Napier Shaw.
9. 'Meteorology': D. Brunt. (Oxford University Press. 1928.)

II. THE WATER

1. 'Oceanic Circulation': *Challenger* Report by Dr. A. Buchan.
2. 'The Ocean': Sir John Murray.
3. 'The Depths of the Ocean': Sir John Murray and Dr. J. Hjort. An excellent general account of oceanography written round a cruise in the *Michael Sars* in the North Atlantic Ocean.
4. 'The Tides and Kindred Phenomena of the Solar System': Sir G. H. Darwin.
5. 'On the Use of Insulated Water-Bottles and Reversing Thermometers': V. W. Ekman, Pub. de Circonstance, No. 23 of the Conseil permanent international pour l'Exploration de la Mer, Copenhagen.
6. 'Short description of a Propeller Current Meter' (in German): V. W. Ekman, Pub. de Circ., No. 24.

Papers on the determination of Salinity and Density.

7. 'Determination of Salinity and Density': D. J. Matthews, Glazebrook's 'Dictionary of Applied Physics', vol. iii, pp. 676 et seq.
8. 'Knudsen's Hydrographical Tables 1901': London, Williams & Norgate, and Copenhagen, G. E. C. Gad.
9. 'Tables for Sea-water under Pressure': V. W. Ekman, Pub. de Circ., No. 49.
10. The Hydrographical Tables appended to 'Dynamic Meteorology and Hydrography': V. Bjerknes, The Carnegie Institute of Washington.
11. 'Contribution to the Calculation of the Distribution of Pressure and Mass in the Sea': (in German) T. H. Hesselberg and H. U. Sverdrup, Bergens Museum Aarbok, 1914–15, No. 14.
12. 'Biological Chemistry and Physics of Sea-water': H. W. Harvey. Cambridge University Press.

The 'Publications de Circonstance' quoted above are published by the Conseil permanent international pour l'Exploration de la Mer, Strandvej 34, Hellerup, Copenhagen.

The Normal Water, Insulated Waterbottle and much other oceanographical apparatus is supplied by Professor Martin Knudsen, Den Polytekniske Læreanstalt, Copenhagen.

III. THE SHORE

The facts relating to the biology of tropical shores are scattered in the literature of the exploration of such seas and coasts. Such books as 'The Three Cruises of the *Blake*', by Alexander Agassiz; 'The Depths of the Ocean,' by Sir John Murray and Dr. Johan Hjort; 'Desert and Water Gardens of the Red Sea,' by Cyril Crossland, will be found interesting reading, while 'The Biology of the Seashore', by F. W. Flattely and C. L. Walton, gives a basis for comparison with temperate shores.

Of more special interest in respect to coral reefs may be mentioned 'Corals and Coral Islands', by James D. Dana, 3rd ed. 1890; 'The Structure and Distribution of Coral Reefs', by Charles Darwin, 3rd ed. 1899; and 'The Coral Reef Problem', Amer. Geogr. Soc., Sp. Pub. 9, by F. M. Davis, 1928. 'The Great Barrier Reef of Australia,' by Savile Kent, is beautifully illustrated, while 'The Fauna and Geography of the Maldive and Laccadive Archipelagoes' is a more accurate account of the animals and plants affecting coral reefs; the volumes from the Department of Marine Biology of the Carnegie Institute of Washington include A. G. Mayor's advances in knowledge up to 1924.

IV. THE PLANTS

1. 'Pflanzenleben der Hochsee': G. Schütt.
2. 'Meeresalgen Deutschlands und Österreichs': F. Hauck.
3. 'Phycologia Brittanica': W. H. Harvey.
4. 'Nereis Borealis-americana': W. H. Harvey.
5. 'Nereis Australis': W. H. Harvey.
6. 'Phycologia Australica': W. H. Harvey.
7. 'Marine Algae of New England': W. G. Farlow.
8. 'Some Aqueous Media for Preserving Algae': Setchell and Osterhout, 'Bot. Gaz.', xxi. 140.
9. 'The Dinoflagellates of Northern Seas: Marie V. Lebour, Marine Biological Association, 1925.

V. THE FLOATING ANIMALS

1. 'The Vertical Distribution of Plankton in the Sea': F. S. Russell, Biological Reviews, vol. ii, 1927.
2. 'Nordisches Plankton': Kiel and Leipzig, 1901–28.
3. 'Conditions of Life in the Sea': J. Johnstone, Cambridge Biol. Series, 1908.
4. 'The Marine Plankton': J. Johnstone, A. Scott, and H. C. Chadwick, Liverpool University Press. 1924.

VI. THE SEA FLOOR

1. 'Deep Sea Deposits': *Challenger* Report, by Murray and Renard.
2. 'Grund Proben': Valdivia Report, by Murray and Philippi.
3. 'Report of Albatros Expedition, 1904–1905': A. Agassiz, in Mem. Mus. Comp. Zool. xxxiii.
4. 'The Marine Deposits of the Southern North Sea': J. O. Borley. Minis. Agric. Fish. Fishery Investigations II, vol. iv, 6, 1923.

VII. ANIMALS OF THE SEA FLOOR

1. 'Grundzüge der marinen Tiergeographie': A. Ortmann.

XII. WHALES

1. 'A Book of Whales': F. E. Beddard. 1900.
2. 'A Whaling Voyage round the Globe (1833–36)': F. D. Bennett. 1840.
3. 'The Cruise of the *Cachalot*, after Sperm-whales': Frank T. Bullen. 1898.
4. 'Whaling Cruise to Baffin's Bay, &c.': A. Hastings Markham. 1874.
5. 'Account of the Arctic Regions, with a history of the Whale-fishery': William Scoresby. 1820.
6. 'Voyage to the Northern Whale-Fishery': William Scoresby. 1823.

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INDEX

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